ニコン「NIKKOR Z 400mm f/2.8 TC VR S」「NIKKOR Z 600mm f/4 TC VR S」の開発

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Development of the ‘NIKKOR Z 400mm f/2.8 TC VR S’ ‘NIKKOR Z 600mm f/4 TC VR S’

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ニコンの最先端技術を結集させ，高解像と美しいボケ味による臨場感あふれる描写力と高速・高精度オートフォーカスを備えた，テレコンバーター内蔵大口径超望遠レンズ「NIKKOR Z 400mm f/2.8 TC VR S」「NIKKOR Z 600mm f/4 TC VR S」をそれぞれ2022年２月，2022年11月に発売した．ここでは，上記２製品の様々な開発要素について説明する．

In 2022, we launched 2 super-telephoto prime lenses with built-in teleconverter, NIKKOR Z 400mm f/2.8 TC VR S and NIKKOR Z 600mm f/4 TC VR S. With cutting edge NIKKOR technologies, we provide photographers outstanding quality pictures that has high resolution and smooth bokeh. Furthermore, the newly developed high speed and high accurate VCM makes sure of that.

In this paper, we introduce some stories developing these lenses, technical features and backgrounds.

Key words ニコンＺマウント，交換レンズ，超望遠レンズ，内蔵テレコンバーター，VCM
Nikon Z mount, interchangeable lens, super-telephoto lens, built-in teleconverter, VCM

1 Introduction

In 2022, Nikon released two Z-mount super-telephoto prime lenses designated as “NIKKOR Z 400mm f/2.8 TC VR S” (hereinafter, “Z400/2.8”) and “NIKKOR Z 600mm f/4 TC VR S” (hereinafter, Z600/4) (Fig. 1). Both these lenses, i.e., the Z400/2.8 and Z600/4, are equipped with a built-in 1.4x teleconverter, whereby the Z400/2.8 is able to switch between focal lengths 400 and 560mm, and the Z600/4 is able to switch between focal lengths 600 and 840mm.

Fig. 1 Top: NIKKOR Z 400mm f/2.8 TC VR S
Bottom: NIKKOR Z 600mm f/4 TC VR S

2 Background of the Built-in Teleconverter

Most telephoto lens use cases involve the application of a teleconverter for extending the focal length. In such cases, it becomes necessary to insert a general-purpose external teleconverter between the lens and camera body after removing them. This kind of setup changes have the potential to result in missed photo opportunities while shooting in the field. Additionally, these changes need to be done with care, particularly during bad weather, to prevent the ingress of moisture into the camera body and avoid water particles on the lens. Therefore, professional photographers always preferred built-in teleconverters for telephoto lenses. To meet this demand, Nikon adopted a built-in teleconverter in the F-mount zoom lens “AF-S NIKKOR 180–400mm f/4E TC1.4 FL ED VR.” However, there was similar demand for such installation in prime lenses as well.

The photograph (Fig. 3) depicts a photographer holding the Z400/2.8 attached to a Z9. The built-in teleconverter switch is located on the right-hand side camera grip (Fig. 2). Placing the switch at a location where it can be operated with the middle finger of the right hand facilitates switching the built-in teleconverter on and off while maintaining the shooting posture. Moreover, regardless of whether the built-in teleconverter is used or not, the user can continue to handle the lens in the usual manner when shooting in the field because the overall length and center of gravity of the lens remain unaltered.

In addition to ease of handling, the built-in teleconverter has a distinct advantage over general-purpose teleconverters in terms of performance. Most often, external teleconverters are designed to maintain the same performance as that of the lens to which they can be attached, whereas built-in teleconverters are designed specifically to match the performance of the specific model of the lens, thereby ensuring improved design performance. Moreover, various adjustments, such as the focus adjustment and the resolution performance inspections, are conducted during the production process for both scenarios, i.e., when the built-in teleconverter is in use and when not in use, to ensure high-quality photographs can be captured regardless of whether the built-in teleconverter is used or not.

Fig. 2 Built-in teleconverter switch

Fig. 3 Handheld shooting using Z400/2.8 and Z9

3 Achieving Both Robustness and Light Weight

During the development of these two lenses, another theme that was emphasized, similar to the inclusion of a built-in teleconverter, was the light weight of the lens barrel. A light weight super-telephoto prime lens is a major advantage during field work as well as with transporting the equipment. The new lenses are approximately 850 and 550 g lighter than the current F-mount models AF-S NIKKOR 400mm f/2.8 FL ED VR (hereinafter, AF-S400/2.8) and AF-S NIKKOR 600mm f/4 FL ED VR (hereinafter, AF-S600/4), respectively.

Developing light weight equipment required the camera system that retains the high image quality and robustness that NIKKOR lenses have cultivated over the years and can be relied upon by photographers. Hence, close attention was given to these aspects.

The structure itself was reviewed relative to conventional lens barrel structures, and the number of parts was reduced while the weight of the parts themselves was also reduced. A key aspect here was the simulation technology that applied data that were aggregated through development and verification activities in the past. This technology and data were utilized to select the parts thicknesses, determine structural strength, and validate appropriate material choice for these purposes to realize a product that was both lightweight and robustness.

For example, reducing the weight of a part requires either reducing its volume or density. Simply reducing the parts thickness will decrease rigidity, and selecting materials with low density will decrease the Young's modulus. Therefore, we attempted to balance the density and Young's modulus by effectively utilizing a combination of several materials, such as aluminum alloys, magnesium alloys, and engineered plastics. This was accomplished by conducting strength analysis repeatedly during the development process using simulations by optimizing material thickness while maintaining structural strength.

Finally, impact tests were carried out with a prototype to confirm the accuracy of the simulations and to guarantee the required strength that is expected when in the hands of users. These investigations aided us in realizing a significantly light weight product while maintaining the robustness, which is the unique selling proposition (USP) of Nikon products, as well as the reliability of Nikon tools that has been cultivated over the several decades.

4 Issues with Built-in Teleconverter and Z Mount

The shift from the F mount to the Z mount necessitated significant revamping of the optical design. This was necessary to maintain an appropriate overall length of the lens barrel and to reduce the weight.

The existence of a Z mount has both advantages and disadvantages in terms of achieving a built-in teleconverter.

One advantage with the Z mount is that the mount aperture becomes larger, which enables more peripheral light to be captured even when a built-in teleconverter is installed.

On the other hand, the increased overall length of the lens barrel due to the short flange back is a disadvantage because it not only increases the mass but also makes its handling more difficult. Certain professional photographic equipment, such as the lenses and camera bodies, are very expensive, and obviously, users are quite concerned about their loss, theft, or damage during transportation.

Consequently, there is strong user demand for carrying lenses on board as carry-on luggage during air travel. This demand is particularly high for expensive super-telephoto lenses. Therefore, lenses that are compact enough to fit in carry-on bags are highly sought after.

However, simply shortening the overall lens barrel length would require each lens to have improved convergence power, which in turn could result in increased mass and compromise its optical performance. Here, the distance from the front lens to the sensor is called the total optical length, and the value obtained by dividing the total optical length by the focal length is called the telephoto ratio. A lower telephoto ratio results in higher aberration caused by the power that converges the light rays, and aberration correction becomes more difficult. Additionally, increasing the convergence power involves approaches such as reducing the radius of curvature of the lens and increasing the refractive index of the glass used in the lens. However, the former approach has a tendency to increase the volume, whereas the latter has a tendency to increase the density of the glass. Evidently, both approaches are counterproductive from the point of view of developing light weight equipment.

In other words, it is imperative that an optimal solution needs to be devised; one that would enable realization of equipment with built-in teleconverter that are significantly lighter by weight, whose overall lens barrel length is low while maintaining improved optical performance.

5 Key Optical Materials and Design Approaches

Chromatic aberration correction is the key to design performance in super-telephoto lenses. Chromatic aberration is a phenomenon in which there are shifts in the image formation position of each color (wavelength) of light that passes through a lens. This shift causes the colors to appear blurry on the photograph. Various types of glass concave and convex lenses are combined in optical design to correct the image formation position of each color. In each era, materials that excel in correcting chromatic aberration, such as extra-low dispersion (ED) glass and fluorite, have been used to evolve super-telephoto lenses.

The reason for the excellent properties of materials such as ED glass and fluorite is due to their anomalous dispersion. Anomalous dispersion, in the context of the design of camera lenses that handle visible light, mainly refers to the behavior of short-wavelength light, such as blue or purple. However, ED glass and fluorite behave differently in comparison to ordinary glass. Therefore, materials with anomalous dispersion can be used in appropriate locations to effectively correct chromatic aberration from red to purple, i.e., throughout the entire visible range.

Furthermore, the present design used short-wavelength refractive (SR) glass, which is a special glass material with anomalous dispersion that has been exclusively developed by the Nikon Group. Although conventional fluorite and ED lenses are also materials with anomalous dispersion in the lower dispersion range, SR lenses have the feature of greatly refracting short-wavelength light, such as blue and purple, in the higher dispersion range. Additionally, its combination with fluorite and ED lenses allows the lens to greatly contribute to chromatic aberration correction throughout the entire visible range. Its lower density also makes it an essential material for designs that align with the current themes of light weight and high performance.

Next, the specific approach using these materials is explained. Conventional F-mount lenses have a lens with almost no refractive power at the front that has played the role of protecting the fluorite that follows. In the present case, this lens, which is made as a convex lens, is used as a combination of two convex lenses, including fluorite at the front part of the lens, adopted to reduce the aberration that occurs, as opposed to its use as a combination of a protective glass + fluorite composition. This allows the lenses that follow to be placed at a longer distance away from the two front lenses, thereby allowing a significant reduction of the lens diameter and leading to a significant reduction in volume and mass. Aberration generally worsens when the lens group in the middle part is moved backwards. However, appropriate placement of the SR lenses and super ED lenses with high aberration correction capabilities in the rear part compensates for the lack of aberration correction in the front part, thus achieving good aberration balance for the entire optical system.

Conventional F-mount lenses use approximately three lenses in the focus group to suppress aberration fluctuations during focusing. Notably, optimizing the lens configuration closer to the object than the focus group enables the suppression of aberration fluctuations during close-up shooting, even when a focus group with fewer lenses is used. The lighter weight of the focus lens also offers more freedom in the focus actuator design, and further efforts could be made in achieving high-speed, high-precision, and quiet operation.

An important element in optical design using a built-in teleconverter is correcting aberrations not only in the entire optical system but also in the lens system as parts of a whole. Specifically, when dividing the camera system into the three parts of ① lens system that is closer to the object than the teleconverter, ② teleconverter section, and ③ camera side behind the teleconverter, this refers to the two parts ① and ②. When the teleconverter expands the focal length, it also expands the aberrations in the optical system. Suppressing the aberration fluctuations during use or non-use of the teleconverter requires suppressing the difference between the level of aberration in ① that occurs during non-use of the teleconverter and the level of aberration in ① that occurs during use of the teleconverter and that is magnified by the magnification of the teleconverter in ② along with the level of aberration in the partial system ②. High optical performance regardless of use of a teleconverter is achieved by proceeding with the design while paying attention to the aberration of the entire optical system as well as the aberration of these partial systems.

Please take a look at the actual photographs to observe the results of the aforementioned design.

The photograph (Fig. 4) exhibits a subject with splashes of water, which is generally prone to significant color bleeding, taken at 600 and 840mm using the built-in teleconverter. The proper chromatic aberration correction accomplished by the special glass allows for the splashes of water to be visible from the maximum aperture, regardless of the built-in teleconverter use. Color bleeding due to chromatic aberration is more likely to occur at shorter shooting distances, such as at 4–5 m, but photographers have praised the lens for its clear depiction regardless of shooting distance.

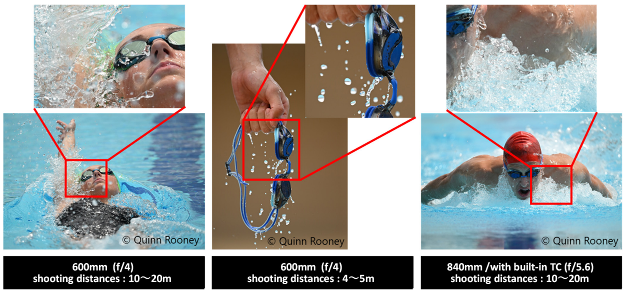

Fig. 4 Effect of chromatic aberration correction

The photograph (Fig. 5) shows the same subject taken at 600 and 840mm using the built-in teleconverter. Even subjects with fine lines, such as animal hair, are depicted in detail at the maximum aperture, with each line individually depicted, and the high resolution that was achieved can be observed regardless of the built-in teleconverter use. There is the illusion of the sheep and shoebill being right in front of the viewer. This expressive power is the appeal of the super-telephoto prime lenses to photographers, who will not be able to resist the temptation to take them out for shooting.

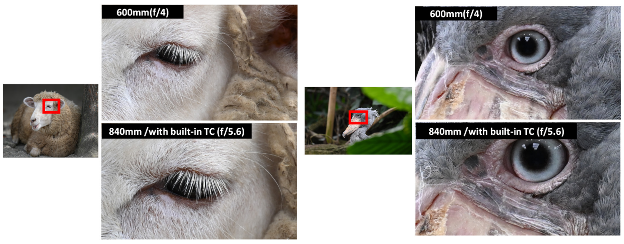

Fig. 5 Image quality when using built-in teleconverter

6 Development of Elemental Technologies That Support Light Weight

In parallel with the design, we investigated technologies for thinning the large-diameter lens in the front and for holding the lens in order to reduce the mass of the lens barrel.

We have previously described chromatic aberration correction during the design of super-telephoto lenses, but maintaining the precision of the lens surface during lens processing and assembly is also a very important element in the manufacturing of super-telephoto lenses. In terms of lens polishing, processing a large-diameter lens with high precision is not only technically difficult to begin with, but the desire to reduce the lens thickness for lightweight equipment further increased the processing difficulty.

There was also the issue of holding this lens securely in the lens chamber. Large-diameter lenses have a large mass themselves, so maintaining performance even when the lens is unintentionally subjected to shock or vibration during field shooting requires mechanisms and assembly conditions for holding the lens securely. The lens needs to be held with sufficient force to prevent its movement, but excessive application of force will cause lens distortion and destroy the precision of the lens surface, which may lead to a degradation of its optical performance. Determining the balance between reliability and performance is crucial here.

To achieve these efforts, we set the goals of light weight equipment and processing accuracy for the lens processing with the technical team members, and we proceeded with the design while receiving feedback from the processing experiment results and checking the balance between performance and mass. The design, manufacturing, and assembly came together for the lens holding mechanism, while simulations and prototypes were used to adopt a structure that maintained high performance while ensuring reliability.

7 Autofocus That Never Misses a Photo Opportunity

Fast-moving subjects such as athletes and wild animals are an indispensable element for shooting scenes with super-telephoto lenses. Super-telephoto lenses require autofocus (AF) performance for accurately capturing the precise moments of such subjects. Although summarized as "AF performance", its output is influenced by various elements. For example, to capture the instance when the ball is passed to another player in the team through a careful pass in a soccer game, the camera needs the explosive power to instantly adjust the focus and capture the scene where the player dribbles past an opponent; the camera requires the tracking power to continue capturing the irregular movement.

A major breakthrough is needed in the focusing unit when designing the present model for meeting the above-mentioned needs. There is a need for the adoption of an actuator that could drive a large lens with superior response and stop it with high precision. Maintaining higher optical performance requires having a mechanism that minimizes the tilt of the focus group. After several design configurations and prototypes, the Silky Swift VCM was born, which uses a VCM that can directly apply the driving force to the lens chamber, a guide mechanism with less backlash and friction, and high-rigidity engineered plastic (Fig. 6).

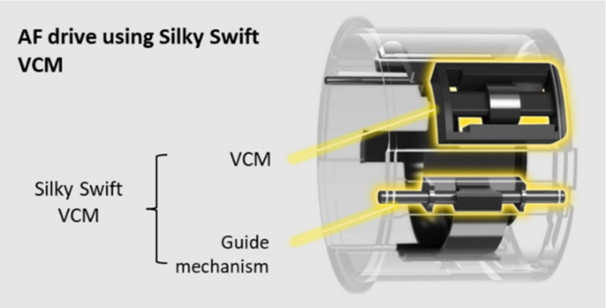

Fig. 6 Silky Swift VCM

Furthermore, the optical ABS encoder that was used as the lens position encoder detects the lens position by reading a precise scale with light, which enables position detection at a resolution approximately 20 times finer than in conventional models. The combination of this encoder with the Silky Swift VCM enables precise position control. This drive system was first installed in the focus lens of the Z400/2.8 and was later used in the Z600/4 as well, with an optimized design that matches the lens arrangement and drive specifications.

This improved the actuator performance of the focus lens, but this alone does not result in improved AF performance. AF accuracy is improved by not only the optical performance of the lens but also the cooperation of the equipment as a camera system, including the Z9's image plane phase difference AF. The combination helps improve the shooting yield of images captured when dealing with subjects that require high-speed, high-precision lens position control, such as the soccer game scenarios mentioned earlier.

8 Excellent Backlight Resistance

The Meso Amorphous Coat, which was first used on the Z400/2.8, is a coating comprising a unique material that was born from elemental development to achieve the highest anti-reflection performance in the history of NIKKOR lenses. The Meso Amorphous Coat has a bulky structure that is formed by connecting particles that are smaller than the Nano Crystal Coat particles to form an amorphous structure. This results in the formation of mesopores (gaps between particles) throughout the film and achieves high film porosity. A refractive index that is even lower than that of Nano Crystal Coat is achieved through the inclusion of air in these mesopores. Furthermore, the precise configuration of a bulky structure comprising fine particles enables a high-porosity, low-scattering film structure that cannot be achieved with Nano Crystal Coat in a simple manner [1].

This results in the material achieving a performance that surpasses Nano Crystal Coat, which has a high anti-reflection effect against oblique incident light. The Meso Amorphous Coat also possesses an anti-reflection effect equal to or greater than that of ARNEO Coat against directly incident light, which renders the developed material the ability to significantly reduce ghosts and flares caused by various incident light.

In the present study, we have understood the respective features of not only the newly-developed Meso Amorphous Coat but also those of the Nano Crystal Coat, ARNEO Coat, and Super Integrated Coating, and their application in the appropriate locations to reduce ghost effects. We also conducted ray tracing simulations at the design stage and optimized the shape and placement of the mechanical parts to prevent ghosts and flare from those parts.

Fig. 7 Example of photograph with strong light source on screen

The photograph (Fig. 7) is an example of a silhouette of a giraffe against the backdrop of a sunset. Clear images with good clarity can be captured even in such scenes thanks to the use of the Meso Amorphous Coat and ARNEO Coat, as well as mechanical parts designed with consideration to ghosts and flare.

9 Operability and Mobility That Do Not Rely on Vision

The Z400/2.8 and Z600/4 were two products designed with a focus on usability that enables professional photographers to use them without stress in their daily work.

Additionally, operating parts such as the various rings, switches, and buttons are implemented. Also included are the lens-function (hereinafter, L-Fn) 2 buttons, Fn ring, control ring, focus ring, L-Fn button, various slide switches, memory set button, and built-in teleconverter switch.

These control elements are configured to provide users a variety of shooting experiences. For example, the Fn ring, installed for the first time in this model, can record different focus positions for each direction of rotation, i.e., to the left or right, and can be assigned the function of instantly calling out the focus position according to changes in the subject. Previous models allowed the focus position call-out function to be assigned to L-Fn2 buttons, but only one focus position can be called out. The present model allows the focus position to be called out with the Fn ring, so different functions such as FX/DX switching can be assigned to the L-Fn2 buttons. This significantly increases the number of compositions and scenes that can be captured while maintaining the shooting position. Assigning the high-resolution zoom to the control ring enables changes to the composition as though a zoom lens were being used, even though it is a prime lens. Since the release of these two models, we have responded to user feedback through firmware upgrades that improved the operability. One such improvement was the swapping of the focus ring and control ring functions. Operating parts have been arranged to achieve a shooting method that defies conventional wisdom, with the hope that users will explore the settings so as to be tailored to them and have a shooting experience with higher yield than ever before.

Several 3D models, prototypes, and mockups were created and tested repeatedly to enable easy operability when used either in the handheld mode or with a tripod. Through this, an arrangement of operating parts that can be used in a variety of ways was accomplished. Careful attention was paid to the design detail of the shape of the parts to ensure that the operating parts are distinguishable merely by touch rather than relying on vision. Furthermore, the operating parts of these two products are identical from the perspective of the camera. Thus, operability, which has been a particular focus of ours, is implemented in a consistent manner across both of these products.

The change in the center of gravity of the lens has also significantly contributed to mobility and handling. The lighter weight of the front lens components and mechanism parts compared to that of the F-mount AF-S400/2.8 and AF-S600/4 resulted in not only a reduced lens barrel weight but also in a significant shift of the center of gravity toward the camera. Consequently, this led to reduced force of inertia when panning the lens in handheld or monopod shooting, thereby enabling smoother changes to the composition and panning shots. Users who actually attach the lens to a camera and take handheld shots will be able to feel the effects that go beyond numbers-based weight reductions.

Even though the Z600/4 has a longer overall product length, the two models have been designed to minimize the difference in the center of gravity between them to ensure that the feel when shooting is consistent. We believe that these products are intuitive and easy to use, even for users who use both models for different occasions depending on the shooting scene.

10 Conclusion

The Z400/2.8 and Z600/4 are lenses that combine mobility, image quality, and functionality. Using them in combination with the built-in teleconverter renders users an enjoyable shooting experience that is similar to switching between two super-telephoto prime lenses without actually changing the equipment.

Many photographers have used these lenses and highly praised them for their operability, image quality, AF performance, and ease of handling. We wish to continue creating products that connect users to new shooting experiences.

References

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