Proc. of SPIE Vol. 0163, Advances in Optical Production Technology, ed. A.B. Scrivener, F.W. Clarke, K.W. Brittan, P. Kutt (Apr 1979) Copyright SPIE

ZOOM LENS SYSTEMS

Alan Ashton
Engineering Manager (Optics) Rank Taylor Hobson
Leicester, United Kingdom

Abstract

The design and manufacture of zoom lenses involves a range of scientific and engineering problems not normally encountered in fixed focal length lens manufacture. This is not solely related to the increased number of elements but also to the manner of use of such lenses. Two lenses are described to illustrate different approaches to the problems. In one lens having a specification of 25-250mm f/3 6 for 35mm cine the zoom action is achieved by sliding movements In the second lens the specification is 20-100mm f/2.8 and the zoom action is obtained by rolling movements The latter lens also achieves a shorter minimum object distance and superior optical performance The lens elements are located in steel cells which are cemented into aluminium carriages using a flexible adhesive so as to obtain improved alignment over a wide temperature range

Introduction

The design and manufacture of zoom lenses is an unusual and fascinating branch of what one might term conventional optics, that is, making lenses. This is because it takes the normal problems of fixed focal length lens manufacture a stage further in complexity and introduces a whole range of other scientific and engineering problems not normally considered. The performance specification for the final assembly brings in many other factors which conflict with the primary optical requirements, so that not only are many more elements and groups of elements needed to meet the optical specification but there are other mechanical constraints which have little to do with achievement of the optical performance

The purpose of a zoom lens is to provide an image of the scene which varies in magnification while remaining in focus at all magnifications and object distances within a specified range The two primary optical principles involved are usually referred to as optical compensation and mechanical compensation Most practical lenses are mechanically compensated with more than one group of elements moving relative to each other and to the fixed members by a variety of laws of motion. The motion is achieved through mechanical linkages or cams All the zoom lenses manufactured by Rank Taylor Hobson are of the mechanically compensated type.

The widest range of use of zoom lenses is in motion picture photography and television broadcasting. These two fields demand the highest image quality and a very wide specification.

In the professional cine field the emphasis is on image quality, very often with manually operated zoom, focus and iris, and a relatively simple adaptation between lens and camera. In TV there are additional requirements arising from the need for remote operation of focus, zoom and for an automatic iris. TV cameras also employ different types of pick-up tube of different image format, very often each camera employs a different type of colour separation prism system (different glass type and path length) so that any lens designed for TV has to be capable of being adapted with alternative rear lens sections to the optical unit This is in addition to the mechanical interfacing between lens and camera

In the cine lens field great attention has to be paid to the smoothness or "feel" of the zoom and focus movements so that slow changes in field of view can be achieved manually without jerkiness One must be able to focus on an object in a precise manner without excessive overshoot but quickly The picture must not show unacceptable defocus as one zooms or changes the direction of zoom The picture must not displace sideways as one changes direction of zoom or focus The centre of the image must not wander as one zooms.

Focus must be held to within ± 50μm and zoom wander within 1% of picture diagonal

All these aspects apply to TV but, since we must offer either manual or high performance servo controls we must have smoothness, implying the use of hard materials, but there is also a severe noise restriction because of the presence of sensitive microphones, implying the use of soft materials

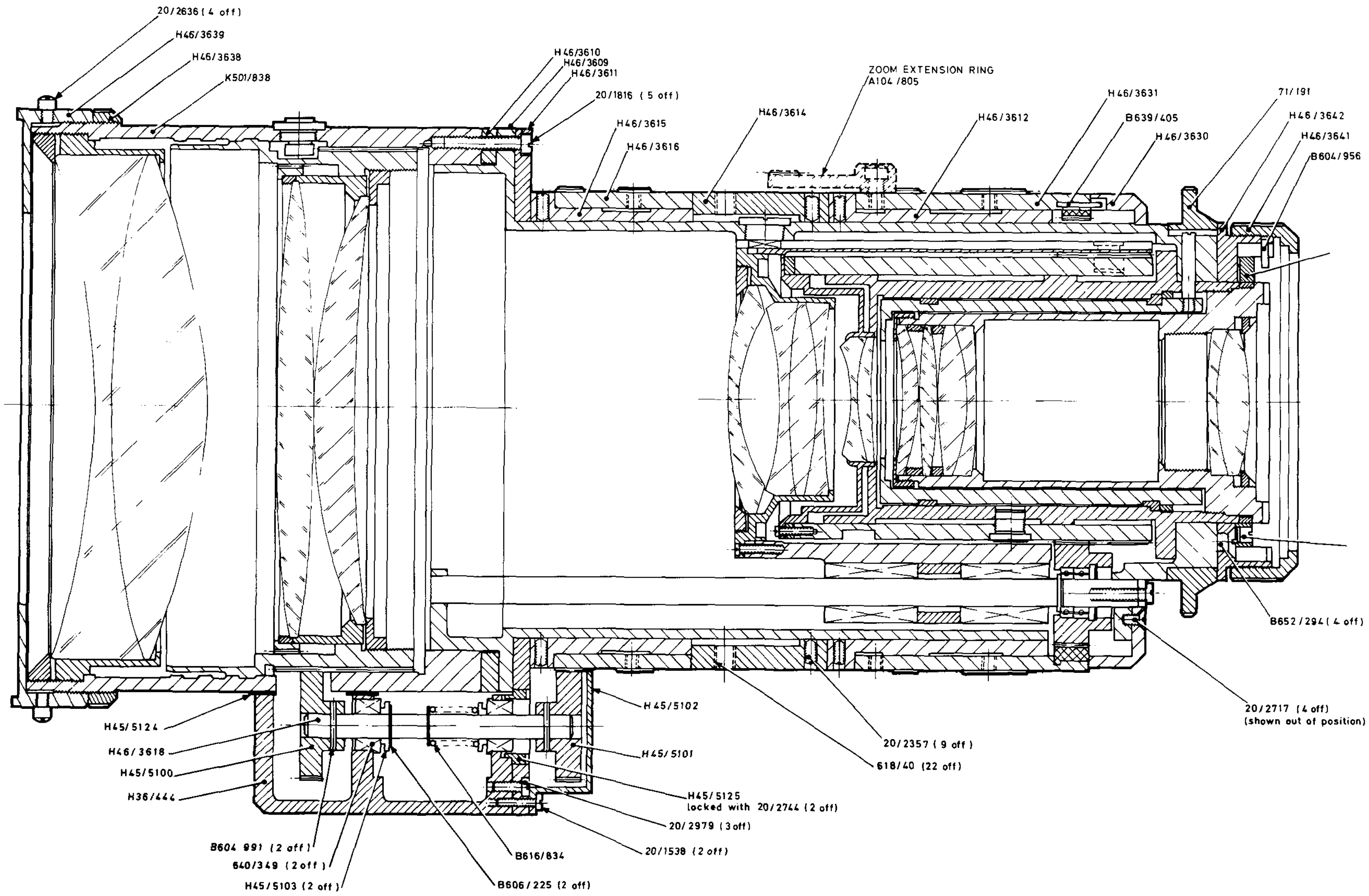

Fig. 1. General assembly of 10·1 zoom lens.

This is a particularly severe problem when one has designed a lens which boasts a very short minimum object distance

The servo and mechanical systems must provide for a very wide range of speeds of zooming, between 1 second and 10 minutes end to end, and for focussing and iris control Therefore low inertia is required of the mechanisms carrying the moving elements but they must also be very rigid so that the alignment of elements does not vary during use or transport All this must be achieved at minimum weight

I will illustrate some optical and mechanical assemblies which have been used to achieve the balance of the various factors which are traded against each other in evolving a zoom lens to perform a particular function

25-250mm f3.6 Zoom Lens

Figure 1 shows a lens which is used in both cine and TV applications. This lens provides a ten to one zoom ratio with a 45° horizontal angle of view at wide angle The lens will focus to 4 ft from the front glass and still hold focus in the zoom The lens itself is about 300mm long and the front glass 150mm diameter

In the figure light travels from left to right The focus unit has a fixed doublet and two moving single elements I will concentrate attention, however, on the means of achieving the zoom action because of the limited time available

The zoom section has two groups One, consisting of a singlet and a cemented triplet, moves over a relatively long distance and the position shown in the figure represents the narrow angle condition This group moves forward to the wide angle position. The second group is just a cemented doublet which has to move forward and then back when going to wide angle. One could say that the first group varies the angle of view and the second restores the focus holding property The aim of the optical design is to achieve stability of the aberrations during zoom in these two groups working together and at levels which can be corrected by the rear unit which consists in this example, of the remaining groups of elements to the right

The rear unit can be removed and another one designed to provide a different final format coverage There is a straight trade-off of focal length and f number. For instance versions of this lens have rear units providing focal length ranges of 40-400mm at f/5.6 on image orthicon, 25-250mm f/3.6 on 35mm cine, 21-210mm f/2.9 on 1¼" plumbicon, 16-160mm f/2.2 on 1" plumbicon or vidicon The object space fields of view and minimum object distance remain the same

Figure 2 shows the zoom sub-assembly and how the movements are imparted to the elements

There are three main components: two sleeves (12/2744 and 12/2745) and a carriage (86/1198) The front zoom group is attached to the front of the carriage This carriage moves along a rod fitted in the lens body parallel to the optical axis. The carriage has ball bushings which are spring loaded sideways to provide a location relative to the axis and a movement which is free from shake. There is a keying slot machined in the bottom of the carriage to prevent rotation

The second group of elements is attached to the front of the component called the zoom ring (12/2745). That is the middle component shown in the figure. The third component is called the iris body (12/2744), this name arises from the fact that the iris leaves are fitted inside it at a later stage The iris body is fixed into the main lens body. It has a cam form cut on its outside This is the actual law of axial motion to be imparted to the zoom ring and the rear zoom group

The zoom ring fits over the iris body and a cam follower located in it engages in the cam slot in the iris body When the zoom ring is rotated by means of the external gear it moves axially thus giving the glasses the required law of displacement

The zoom carriage also has a cam follower, not shown, fixed into it This engages in another cam slot machined on the outside of the zoom ring. Therefore, as the zoom ring is rotated by the gear it imparts a further axial motion to the zoom carriage. The zoom carriage therefore moves according to the sum of the two cam forms

In designing the lens both optically and mechanically, it is important to ensure that the helix angle of the cam varies smoothly and is no where so great as to require excessive torque to drive the carriage and sleeves back and forth. This is vital to obtaining smooth movements and minimising servo power requirements

The two right hand components are machined to form a sub-assembly. The inner bore of

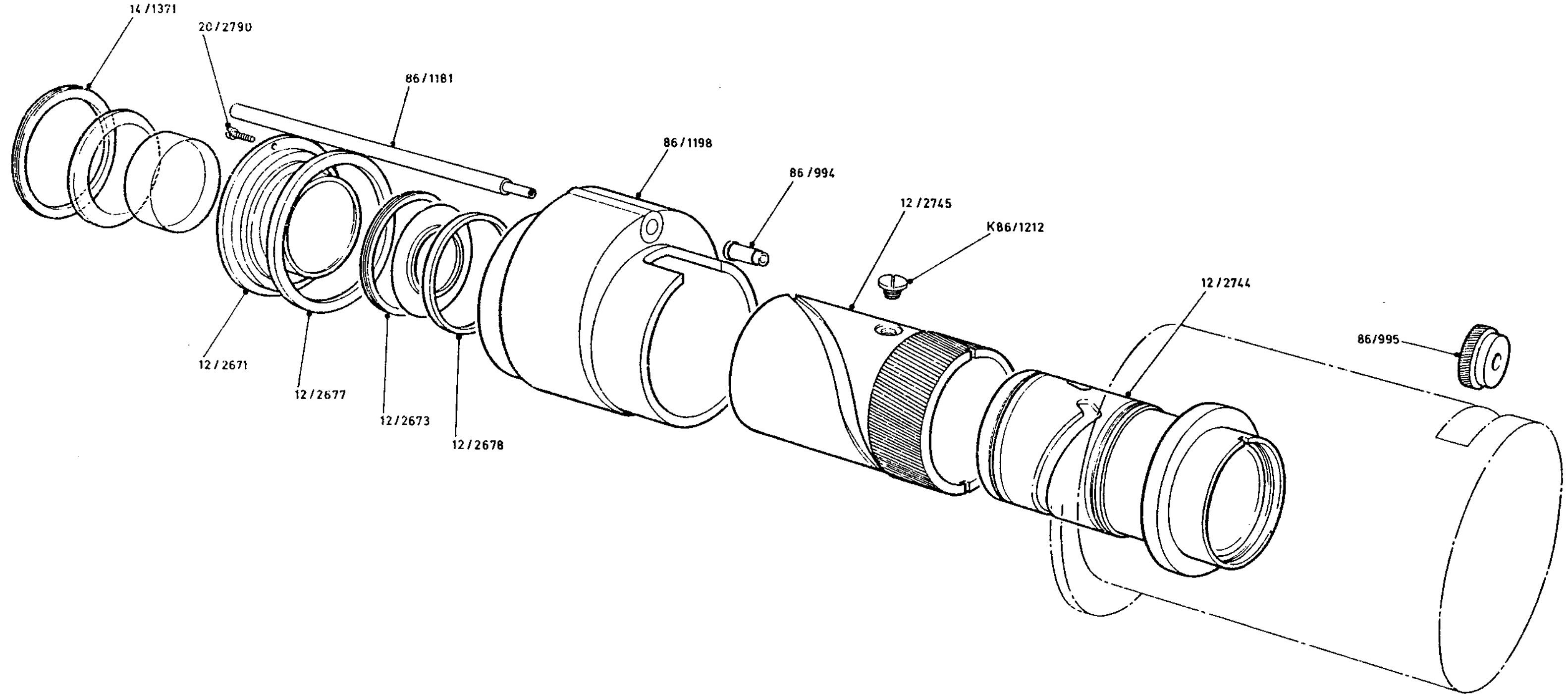

Fig. 2. Exploded view of zoom section of lens shown in Fig. 1.

the zoom ring being hard anodised and honed round and parallel The iris body has raised rings on its outer diameter and these are diamond turned to fit the zoom ring The permissible clearance is between 007 and 01mm A clearance less than this gives an excessive torque requirement and poor wear characteristics Too great a clearance gives rise to lateral movement of the rear zoom elements when reversing zoom, this shows up as picture movement or jump There also appears to be sufficient tilt to give an apparent axial movement which shows as loss of focus on reversing zoom, we refer to this as optical backlash to distinguish it from the purely mechanical backlash associated with gearing. The tolerance is therefore a compromise of the optical and mechanical requirements The iris body sub-assembly is a very difficult component to make as it has so many processes

The cam slots are produced by diamond milling from a master cam form A diamond milling cutter rotating on an air bearing spindle is used to obtain the final cam form, width and surface finish. Cam followers are made of polyurethane and must fit the cam slot without clearance but without excessive tightness Once again the compromise between the optical backlash effects are balanced against torque and smoothness.

Further information concerning this lens and its optical principle can be obtained from Reference (1)

20-100mm f/2.8 Zoom Lens

In the second example shown in Figure 3, the lens is of about the same overall size as the previous lens but has a quite different optical specification It aims to provide a wider angle, a higher relative aperture and closer minimum object distance for 35mm cine The lens provides these aspects of specification at the expense of zoom ratio which is 5:1 It has a horizontal angle of view of 58° at wide angle and focusses to within ·35 metres, 13 inches, of the front glass at an aperture of f/2 8 Therefore it gives 20-100mm f/2 8 compared to the 25-250mm f/3 6 of the first lens

To obtain these features a different optical construction is used The front focussing section is a combination of fixed and moving members capable of accepting the wide angle The zoom section has three groups The first and third move as a pair and the inner group moves in the opposite direction In this design the function of change of magnification is shared more equally between the moving groups. Each having approximately the same amount of travel The mechanical arrangement has to be designed to link the first and third zoom groups rigidly as well as providing all the other movements and locations

There is a greater weight of glass to be moved than in the previous lens and sliding movements would have very high torque requirements

In this lens the zoom action is achieved without the sliding action of the previous example. All the moving elements are mounted in carriages having rollers This reduces the need for lubrication and gives much lower torque. There are two carriages. The larger, outer zoom carriage carries the first and third groups, the inner carriage carries the second group The carriages have large cut-outs to reduce weight

The carriages roll inside the main body which has diamond turned internal bores There are two pairs of rollers set at 120° apart on the circumference of each carriage and another single roller, centrally placed opposite them which runs on a flat spring attached to the inside of the main body This maintains the main rollers in contact with the precise bores of the body.

The spiral cam forms are cut in a separate drive ring which fits over the outside of the main body and runs on ball races. Cam followers attached to the carriages pass through axial slots in the main body and run in the two cam tracks Each of the cam followers employs two rollers which are spring loaded apart so as to run on opposite sides of the cam track and thus eliminate the optical backlash referred to earlier

In the previous example the lens elements were located in aluminium cells by means of spacers and clamp rings The cells then locate directly in the aluminium carriage and sleeves

In the second lens an improved alignment of the optical system is achieved over a wide temperature range by locating the glasses in steel cells with smaller clearances on the diameter permitted by the closer match of coefficients of thermal expansion of glass and steel The cells are initially centred to the carriage and roller diameters by means of jigs, they are then cemented into place with a flexible adhesive After the adhesive has set and the sub-assemblies have been removed from the jigs, the glasses and spacers are assembled directly into the steel cells and retained by clamp rings

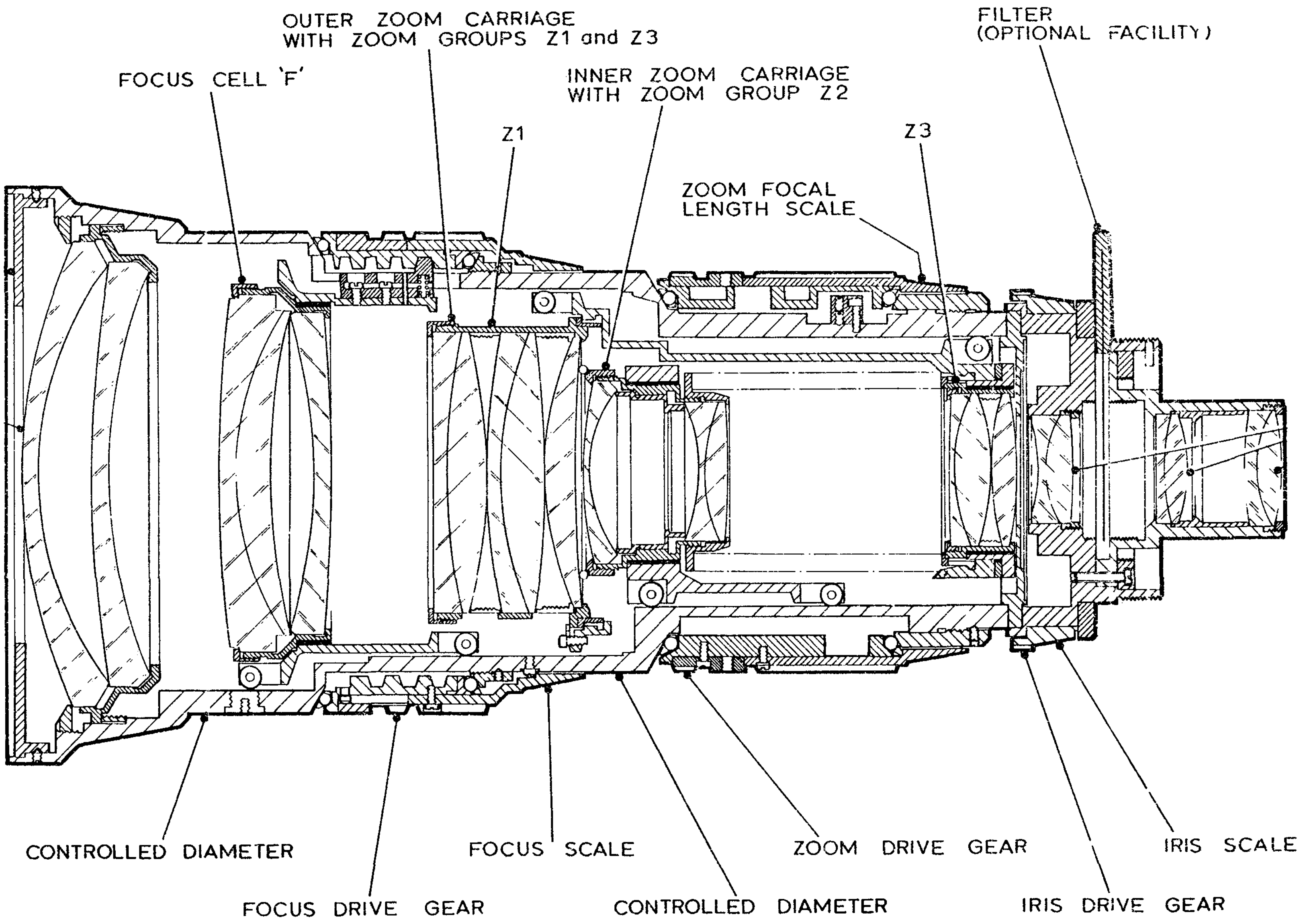

Fig. 3. General assembly of 5 1 zoom lens.

The carriage rollers are made of Tufnol and this material was chosen as a compromise to achieve quietness and smoothness while retaining alignment of the carriages relative to the lens body axis This has been a particularly difficult material to choose and we are still trying new materials as they appear on the market

The cost of this lens is much greater than the first example but its wider specification enables it to command greater numbers of sales despite the shorter zoom range Further information about this and similar lenses can be obtained from Reference (2)

I have been able to show only two examples of the many ways in which zoom lenses can be constructed and neither of these is an ideal solution to the problem. There remain many challenging problems in the optical and mechanical design and manufacture of zoom lenses and I hope that I have been able to show some of the fascination of this subject.

References

1. U S. Patt 3,736,048

2. Cook, G H., and Laurent, F.R , "Recent Trends and Developments of Zoom Lenses", Jour SMPTE 80: 631-634, August 1971.