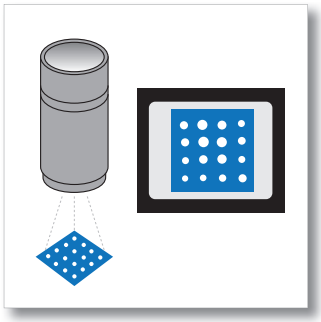
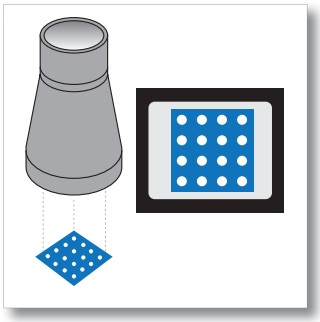
Telecentric lenses – first a little theory

Why do we need telecentric lenses in optical measuring instruments? Imagine a plate with a number of holes where all twelve holes are visible within the field of view of an objective lens. With a standard optical system (entocentric optical system) we would experience perspective distortion as shown in the illustration at the left.

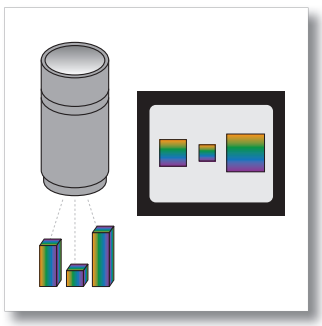


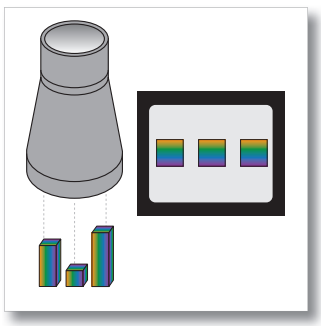


Since with telecentric optical systems the opening angle is zero degrees within a certain range, chief rays are absolutely parallel in the ideal case and the image is depicted without any perspective error i.e. the chief rays are shown parallel to one another. Expressed in another manner: The telecentric optical system reconstructs the image perpendicularly at the edge of the image as well as in the middle, or: The optical system "looks" into the holes at the edge absolutely straight instead of at an angle.

A further, very important reason is that telecentric lenses offer the same reproduction scale even in the Z direction (axial) within a defined range. Imagine a plate equipped with objects of different heights to be measured within one field of vision.

At the left the illustration below shows that the three objects with different heights exhibit different sizes with a standard objective lens. The model at the right shows the result with a telecentric lens. Expressed in simple terms, this means, that lenses which are sometimes closer and sometimes further away do not indicate any difference in the distance measured. However this is true only as long as the areas are in the telecentric range, which, for its part, is located within the depth-of-field range, however is not identical to it. Telecentric lenses are also interesting when parts are fed to the optical system on belts and the positioning is not precisely reproducible. Here the differences in height are again compensated in the telecentric range. Telecentric optics are also essential for measuring holes (top/bottom).





Basic information on telecentricity

Object space telecentricity:

Object space telecentricity is used to depict objects without perspective distortion. The entrance pupil is located at infinity, so that the chief rays in the object space are parallel to the optical axis. For this reason the front lens must be at least as large as the object to be represented. A further property of this this optical beam is that the image scale does not change when the object is shifted axially. The image always appears the same size regardless of the distance to the object. However it does go out of focus when the object is located outside the ideal object plane. This characteristic is used in measurement lenses to allow a certain tolerance range for the specimen. The tolerable distance range is determined by the depth of field and is specified in the data sheets. With microscopes the constant image scale allows easy focus. On the object side the telecentric optical beam can be realized most simply by a simple convex lens with aperture diaphragm in the focal plane in the image space.

Image space telecentricity:

Image space telecentricity services primarily to ensure that the chief rays are parallel to one another. It is used, among other applications, for digital camera lenses to prevent pixel vignetting. The exit pupil is located at infinity, so that the chief rays all strike the image plate perpendicularly. The simplest design consists of a single convex lens with aperture diaphragm in the focal plane in the object space.

Double telecentricity:

Double telecentricity is a combination of object-space and image-space telecentricity. Such lenses are used particularly for measuring technology, however, they are also used in photolithographic production processes. The entrance and exit pupils are located at infinity, so that the system is afocal. In contrast to purely object-space telecentricity, the tolerable object position is not limited here by the depth of field. It is possible to refocus the image plate without changing the size of the image. The simplest design for this consists of two convex lenses with an aperture diaphragm located in between. The distance between a lens and the aperture diaphragm must be equal to the specific focal length. Theoretically a double telecentric lens has no aberration such as distortion. (Source: Gottfried Schröder: Technische Optik [Technical Optics], Vogel-Verlag Würzburg 1977, ISBN 3-8023-0067-X)

Telecentric lighting:

Telecentric lighting is a special form of focussed lighting with strong directional properties. This application is accomplished almost exclusively with transmitted light. A light source (usually LED) of known, small illumination aperture is positioned in the focal plane of the light's optical system. The result: Parallel chief rays. Telecentric lighting is not parallel lighting (defined aperture). This makes it considerably less sensitive to vibration or maladjustment.

Telecentric lights supply a very homogeneous, high contrast illumination of the field of vision. It is always necessary to use it in combination with telecentric lenses, because with an entocentric lens, the light source appears to be located at infinity due to the parallel chief rays. Blue is used primarily as the light source wave length (maximum accuracy) due to the minimal diffraction. The highly directional properties of telecentric lighting allow it to suppress extraneous light well.

Application:

In combination with telecentric lenses wherever bright, high contrast illumination is required and it where it is necessary to precisely recognize or measure objects, which are difficult to handle optically.
The distinguished preferred direction of the light rays requires exact focussing. For this reason telecentric lights require a solid, adjustable mount. Calibration of the light aperture and image aperture is the primary factor determining the position of the edge location when using telecentric components. The products below are all object-space telecentric optical elements.

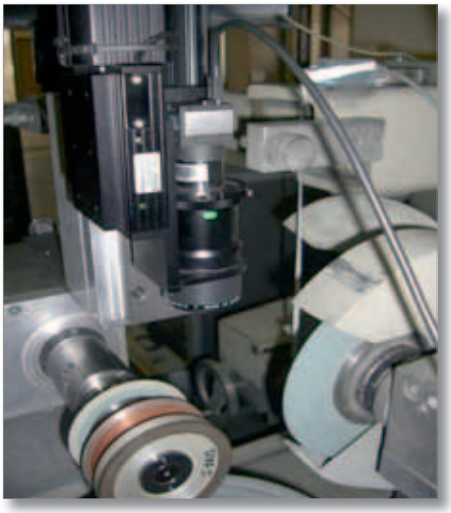
TZS-MOT: Motor-driven telecentric zoom lens

A frequently occurring problem is that of a telecentric lens with fixed focal length cannot satisfy all testing and measuring requirements In such cases it is possible to use the TZS-MOT with its ten reproducible, motor-driven zoom stages. Various expansion stages are available. The lens is laid out for a maximum sensor size of 2/3". When combined with a 1/3" sensor with converter or a sensor smaller than 1/3" is used, it is necessary to check the image quality previously.

The TZS-MOT has two motion axes. A 25 mm axis for the magnification factor and a 300 mm axis for focussing. The zoom factor is approx. 4:1. The expansion stage with automatic converter changer has a zoom factor of approx. 10:1. The zoom ranges are subdivided into 10 practical magnification stages in the Metric measuring software.

Control is possible over an RS 232 interface. Required power supply: 24 V / 2.5 A for both axes together. A single patch cable is required for the power supply and control for the second axis.

Applications:



Among others, grinding wheels, circular saws and parts with similar shape can be measured with this systems as an alternative to using a profile projector. In combination with the Metric MT and DXF overlay function, the parts can be compared or measured using the specific function. The Excel report system ensures simple and quick documentation.

TZS-MOT in housing

The illustrations show the TZS-MOT in a sealed housing. Drawings are available on request. This system is suitable for installation in grinding machines. Outer dimensions approx. 175 x 175 x 630 mm (not including cable gland). The base plate has six mounting holes with M8 thread and depth of 8 mm. The non-reflecting, hardened glass plate can be changed easily without opening the housing. All screws used are a titanium allow. Weight approx. 17 kg. A telecentric light source is required for light from below.

Technical data, TZS-MOT

The working distance from the front of the lens to the object is approx. 135 mm at maximum magnification. With the housing version the distance is 128 mm from the front of the housing. These are standard values. Changes possible on request.

The housing version is completely calibrated and adjusted before shipment. The OEM ver-

sion without housing can be calibrated and adjusted before shipment, if desired. Naturally corrections can be made easily by the operator after installation. The machine is aligned at the maximum magnification stage. The reproducibility for the centring is +/- 1 pixel. The reproducibility for calibration is 0.1%. Cable lengths outside housing: USB camera cable 4.0 m, RS 232 cable: 4.5 m.

Image field tab

The technical data is subject to normal variations in the optical tolerances. The image fields should have a tolerance range of +/- 5%.

Image fields / sensor size	1/2" Chip	1/3" Chip
without converter	13 - 52 mm	9 - 36 mm
with 0.75x converter	17 - 70 mm	12 - 49 mm
with 2.0x converter	6.5 - 16 mm	4.5 - 11 mm
with 0.75x and 2.0x converter	6.5 - 60 mm	4.5 - 42 mm

The lens is laid out for a maximum sensor size of 2/3". When a 1/3" camera is used the corresponding values can be calculated by multiplying the 1/3" camera value by 2.

Pixel table

The table shows the pixel resolution for the most common cameras. Please observe that the although the number of pixels determines the optical resolution, this has nothing to do with the pixel size of the camera sensor. On sensors with pixel size < 5 µm, the image quality should be checked.

Image fields / Pixel resolution	1280 x 1024	1600 x 1200	2048 x 1536
13 - 52 mm	10.0 - 40.0 µm	8.0 - 32.0 µm	6.5 - 25.0 µm
9 - 36 mm	7.0 - 28.0 µm	5.5 - 22.0 µm	4.5 - 17.5 µm
17 - 70 mm	13.0 - 55.0 µm	11 - 44.0 µm	6.5 - 34.0 µm
12 - 49 mm	9.5 - 38.5 µm	7.5 - 31.0 µm	6.0 - 24.0 µm
6.5 - 26 mm	5.0 - 20.0 µm	4.0 - 16.0 µm	3.0 - 13.0 µm
4.5 - 11 mm	3.5 - 9.0 µm	3.0 - 7.0 µm	2.0 - 5.5 µm
6.5 - 60 mm	5.0 - 50.0 µm	4.0 - 38.0 µm	3.0 - 30.0 µm
4.5 - 42 mm	3.5 - 33.0 µm	3.0 - 26.0 µm	2.0 - 21.0 µm

The lens is laid out for a maximum sensor size of 2/3". When a 2/3" camera is used the corresponding values can be calculated by multiplying the 1/3" camera value by 2.

Prices on request.

TZS-MOT-XY

One example of stationary use of the TZS MOT is in combination with a cross table with measuring range of 200 x 100 mm and an integrated telecentric bottom light. Here the XY coordinates for the cross table are read out by the Metric MT measuring software. The 10 different zoom stages are also controlled by the Metric MT software. In principle this is a modern type of profile projector. The difference in relation to the conventional versions is the simple measurement in the field of view, the possibility of using DXF or vectorized PDF files as overlays and quickly transferring images and readings to Excel templates, created to meet your own demands, by simply pressing a button. The system is available with or without housing and with various sizes of measuring tables.

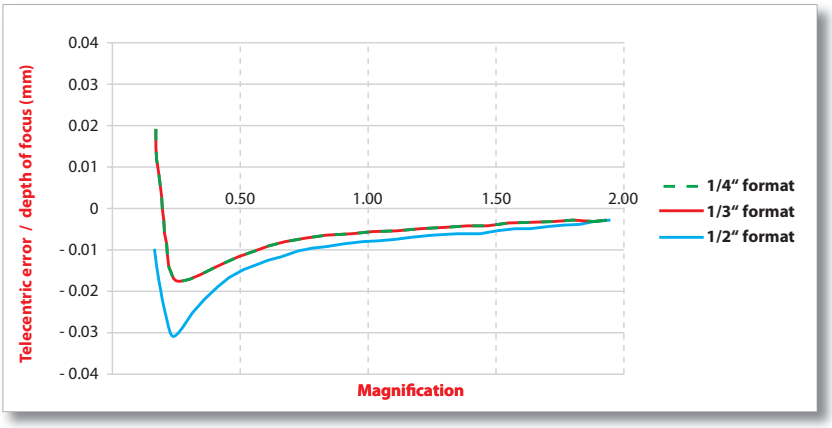
Prices on request.

TZS-M: Manual telecentric zoom lens

An alternative to the motor driven version is the TZS-M. As with the standard grid zoom systems in the NAV-12000 series, this 12x zoom lens has 14 fixed stages which can be calibrated and saved in the Metric measuring software. It is not permissible to change the working distance (end of lens to object) of 188 mm The zoom range covers a field of vision of 4 mm to 50 mm The object depth of field varies in this range from 1.3 mm to 38.8 mm. Complete technical details are given in the matrix below.

All totalled four versions are available: TZS-M with or without coaxial light feature as well as TZS-M with or without coaxial light feature in 90° design. The system with defection mirror was developed to save space when installed in machines.

Frequently the manual systems are used for upgrading grinding machines. Appropriate mounting devices and guide rails are available for such applications. As an alternative we can supply complete systems with or without cross table as state-of-the-art version of a profile projector.

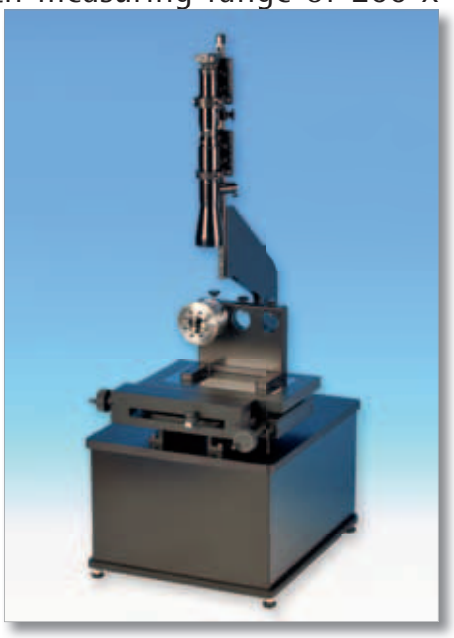


Optical magnification	Telecentric error (Degree) 1/4" Format	1/3" Format	1/2" Format	Object N.A.	Image N.A.	Object depth of field (mm) (mm)	Telecentric error (mm) 1/4" Format	1/3" Format	1/2" Format	Lens size 1/4" Format	1/3" Format	1/2" Format	Approx. MTF (lp/mm)	Resolvable Features (microns)
0.16	0.05	0.06	-0.03	0.005	0.032	38.8	0.018	0.020	-0.009	25.0	37.3	49.7	15	33
0.23	-0.10	-0.09	-0.18	0.007	0.031	19.4	-0.017	-0.016	-0.030	17.4	26.1	34.8	22	23
0.33	-0.19	-0.18	-0.27	0.010	0.030	10.3	-0.016	-0.016	-0.024	12.1	18.2	24.3	30	17
0.47	-0.23	-0.23	-0.31	0.013	0.028	6.0	-0.012	-0.012	-0.016	8.5	12.8	17.0	39	13
0.67	-0.25	-0.25	-0.34	0.016	0.024	3.8	-0.008	-0.008	-0.011	5.9	8.9	11.9	49	10
0.96	-0.27	-0.27	-0.36	0.020	0.021	2.6	-0.006	-0.006	-0.008	4.2	6.3	8.4	59	8
1.36	-0.29	-0.29	-0.38	0.024	0.017	1.8	-0.004	-0.005	-0.006	2.9	4.4	5.9	71	7
1.94	-0.25	-0.24	-0.29	0.028	0.015	1.3	-0.003	-0.003	-0.003	2.1	3.1	4.1	84	6

Distortion <0.1% for all magnification factors. Working distance = 188 mm for all magnification factors

TZS-M-XY

One example of stationary use of the TZS M is in combination with a cross measuring table with measuring range of 200 x 100 mm and an integrated telecentric bottom light. Here the XY coordinates for the cross table are read out by the Metric MT measuring software. In principle this is a modern type of profile projector. The difference in relation to the conventional versions is the simple measurement in the field of view, the possibility of using DXF or vectorized PDF files as overlays and quickly transferring images and readings to Excel templates, created to meet your own demands, by simply pressing a button. The system is available with or without housing and with various sizes of measuring tables.



Prices on request.

IMPORTANT:

The two versions, TZS-MOT and TZS-M, are put together according to customer requirements as one optical unit with software or as a complete system with stand, bottom light and cross table. Due to the many possibilities we have limited our description to only complete system only.

It is not always necessary or practical to use a zoom lens. In the case of objects, which always have the same or similar shape, a telecentric lens with fixed focal length may be more practical for technical and/or financial reasons. To allow us to put together the optimal system for your requirements please make an appointment with us for detailed consultation or demonstration.