The Mechanical Tube Length – A Short Introduction

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The mechanical tube length is the distance between the flange of the objective lens (also known as the shoulder of the objective) and the seating surface on which the eyepiece rests (see Figure 1). In the case of a simple monocular microscope (e.g. the Leitz LL from 1950), the mechanical tube length is equal to the actual physical length of the tube. But for most research microscopes, the effect of the tube lens (or tube lenses) must be taken into account when measuring the effective, mechanical tube length.

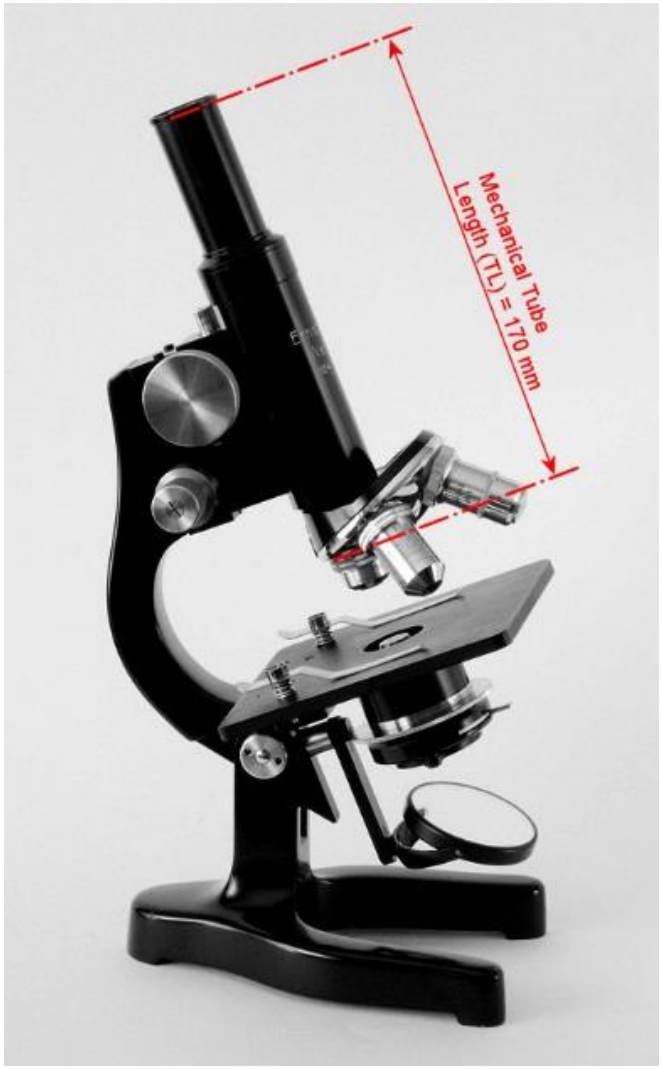

Figure 1: Leitz LL student microscope from 1950.

Provisions to add certain accessories force microscope makers to build microscopes with a longer finite tube length than the mechanical tube length required for correcting their optical system (e.g. longer than 170 mm). As a result, for each such accessory in a finite system, optical elements (known as a tube lens) must be added to bring the tube length precisely back to its proper value (e.g. 170 mm).

Using an objective turret for transmitted light observations, the Leitz Ortholux research microscope uses one of several different tube lenses to adjust the actual physical length of its 223 mm long tube to a desired norm (see image on cover page). Hereby, the actual physical length of the tube is defined as the measured length without considering any optical components inside the tube. To adjust to a mechanical tube length of 170 mm, the Ortholux uses the 170/223 tube lens. This concave tube lens leads to an unwanted extra magnification factor that commonly plagues microscopes designed for the finite mechanical tube length. To provide the so-called infinity tube length, the tube lens ∞/223 must be used.

The following table (see Table 1) lists tube length parameters published by various microscope manufactures.

*Table 1: Tube length parameters. R. P. Loveland, p. 56 from Photomicrography – A Comprehensive Treatise, Volume 1, John Wiley & Sons, Inc. (1970) [**1**].*

Make	Mechanical Tube Length (in mm)	Δ in mm (location of intermediate image plane in mm)	Remarks
Bausch & Lomb Inc.	**160**	**11**	**Biological**
	215	**11**	**Metallographic** (e.g. Dynoptic Labroscope Model DMETR)
American Optical Co.	**160**	**11.3**	**Biological**
	180	**11.3**	**Metallographic**
	∞	**11.3**	**Series 10 and 11 microscopes**
Ernst Leitz GmbH	**170**	**18**	**Biological** (e.g. Ortholux, Orthoplan)
	185	**18**	**Ultropak**
	215	**18**	**Ore microscope**
	∞	**18**	**Metallographic** (e.g. Metalloplan-HL)
Zeiss (Oberkochen)	**160**	**10**	**Old value of Δ = 13 mm**
DIN 58887	**160**	**10**	**Since 1976 also Leitz with the Dialux 20**

The symbol ∞ indicates an "infinite tube length". In this case a special relay lens (or telescopic objective) located inside the body tube of the microscope focuses the collimated beam from the objective to form the intermediate image (or primary image). The infinite tube length design allows for more flexibility in microscopy design.

In the following, we limit our observations to microscopes using objectives for the finite tube length (such as 170mm or 160mm). Microscopes using infinity-corrected objectives (e.g. Nikon Eclipse series microscopes or the Leitz objectives for episcopic illumination) are not discussed.

The combination of tube lens and objective is responsible to generate an intermediate or primary image of the specimen at the fixed diaphragm of the eyepiece or photo relay lens. It is interesting to note that for an optical system that provides all necessary corrections inside the objective/tube lens combination,

the intermediate image can directly be projected onto the image sensor without any loss of image quality (e.g. Nikon Eclipse series microscopes using the CFI_{60} optical system).

For many microscope designs (e.g. Leitz Orthoplan and Leitz Ortholux II) the optical tube length, which defines the exact location of the intermediate image below the shoulder of the ocular, is proprietary. While optical tube length is defined as the distance between the objective rear focal plane and the intermediate image plane at the fixed diaphragm of the eyepiece, it is often measured as the distance between the shoulder of the objective and the intermediate image plane.

The following information relates to Leitz microscopes. – In 1976, with the introduction of the Leitz Dialux 20, Leitz adopted German Standard Commission DIN 58887. DIN 58887 recommends a mechanical tube length (TL) of 160 mm. The Leitz Inter-Office Memorandum No. 84 [**2**] clearly states that in most cases objectives designed for a mechanical tube length of 160 mm can successfully be used on the older Leitz microscopes, which use a 170 mm mechanical tube length. Of course, the oculars designed for a 170 mm tube length must be used in all cases. In a nutshell, the reason for this backward compatibility is the fact that the older Leitz microscopes use an optical tube length (or image distance) of 152 mm, which is just 2 mm longer than the one proposed by DIN 58887 (150 mm). (See Figure 2 for details.)

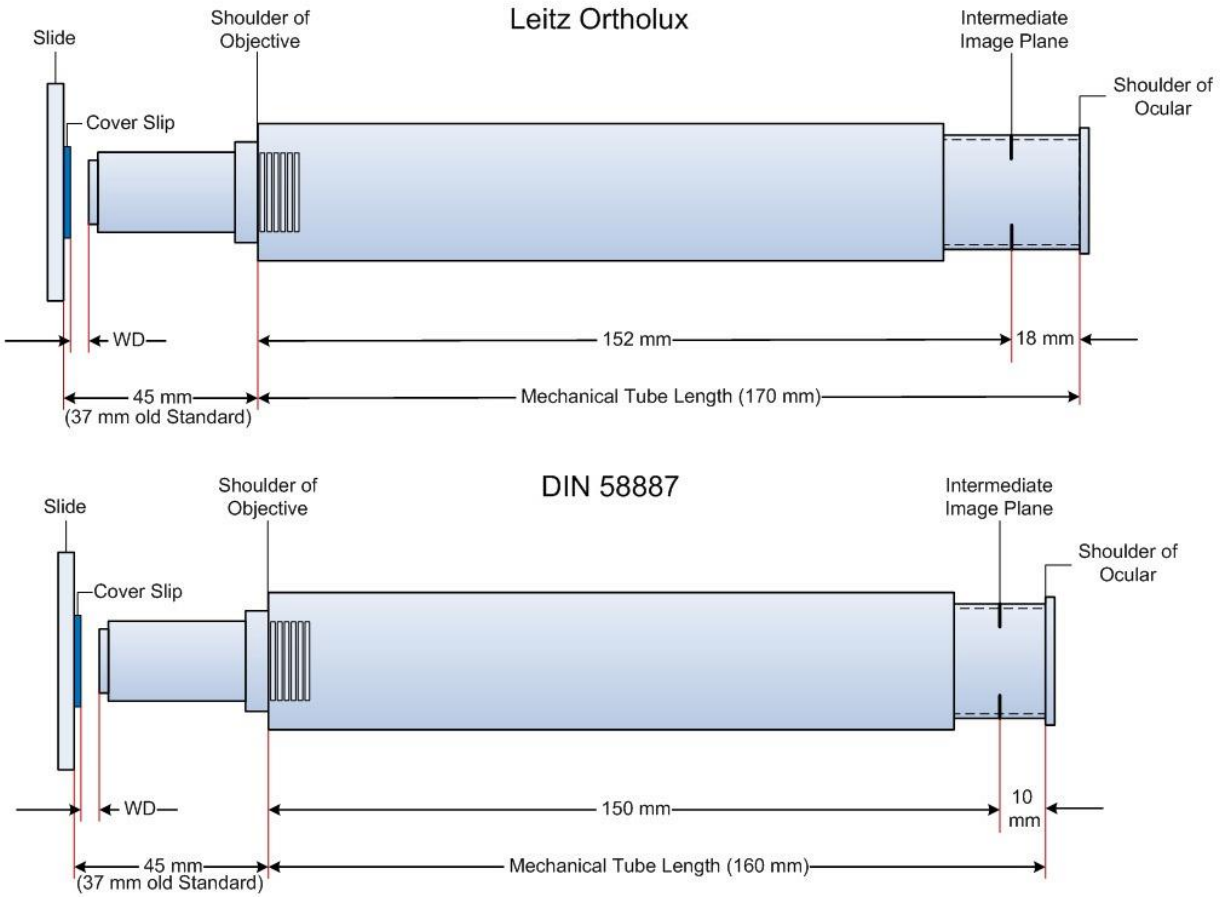

Figure 2: Schematic drawing showing mechanical tube length.

For objectives with a magnification larger than 1:16, the 2 mm displacement of the intermediary image has no noticeable effect on image quality. Roger P. Loveland plotted the tolerance to tube length change

versus objective NA in his excellent book about photomicrography [**1**]. Loveland concludes that the tolerance to change of tube length is affected only by the numerical aperture NA of the objective. Every dry lens with an NA of 0.80 or less should cope very well with a 2 mm difference in image distance. Even better, a difference of just 2 mm does not impact image formation when oil immersion objectives are used. The reason that Leitz does not recommend using objectives with a magnification of less than 1:16 is most likely due to the fact that one cannot maintain parfocality. If parfocality is not desired, even lower power objectives designed for a 160 mm TL could be used.

From the same Inter-Office Memorandum we can learn that newer oculars should not be used on older Leitz microscopes. Of course, when using an adjustable monocular viewing port, one may still be able to use newer Leitz oculars by appropriately reducing the mechanical tube length.

Figure 3: Leitz PLEZY adapter.

Already many years prior to 1976, during the "glory days" of the black microscope stands, Leitz offered objectives with two different parfocal distances. The older objectives use a 37 mm parfocal distance ("short barrel") while the newer ones were designed for a 45 mm parfocal distance. In order to combine the two different types on the same nose piece (objective turret), Leitz offered special adapters called PLEZY (see Figure 3) and FLU-PLEZY (also referred to as PLEZY-FLU).The PLEZY and FLU-PLEZY contain a lens that corrects for the 8 mm extension. Without such a lens, the optical tube length will be increased by 8 mm (significantly more than just 2 mm). Such a large increase in optical tube length would most certainly degrade image quality. The higher the NA of the objective the more would be the impact on image quality (see [**1**]).

The difference between the FLU-PLEZY (Leitz number 519 382) and the PLEZY (Leitz number 519 164) is that the FLU-PLEZY offers better transmission for shorter wavelengths, making it more suitable for fluorescence microscopy using episcopic illumination. An additional designation ‘P’ indicates that the glass inside the adapter is free of stress birefringence, which makes such an adapter suitable for polarized light microscopy.

References

[**1**] R. P. Loveland, p. 59, Figure 2-2 "Tolerance to tube length change versus objective NA." in Photomicrography – A Comprehensive Treatise, Volume 1, John Wiley & Sons, Inc. (1970).

[**2**] Leitz Inter-Office Memorandum (available at http://www.science-info.net/docs/leitz/Leitz-160mm-Memo.pdf) from September 30, 1976 entitled "160 mm Mechanical Tube Length".