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# EXAMPLES OF THE CONSTRUCTIONS OF INSTRUMENTS FOR INCLINATION MEASUREMENT OF THE OBSERVATION PILLARS (CLINOMETERS)

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**Abstract:** Conceptions of instruments for inclination measurement of the observation pillars are presented in the paper. Examples of the construction prepared by authors allow designate an angular and linear inclination of the clinometers located in the geodynamical networks in the Sudety Mts. It makes possible to determine the size of clinometers' self movements as well as considering them in other measurements.

**Key words:** inclination observations, self movements, clinometers, fiber optical and laser technology

## 1. INTRODUCTION

Points of the geodetic networks on the research areas are marked as observation pillars, equipped with metal head at top part. The most important element of the head is bush for forced centring of the intruments. Bushes installed in the head of the pillars must be characterized by high quality of processing, enabling forced centring with ±0,05mm precise. During the process of bush making with unprecised treatment as well as during fixing with metal head the summary errors of made and fixing can cause the following changes of the projected shape (fig. 1):

– ovalness (fig. 1, a)
– conicalness (fig. 1, b)
– local deformation of walls (fig. 1, c)
– non orthogonality of bush axis to the head plain (fig. 1, d)
– barrel shape
– mechanical defects (barb, scratch, etc)

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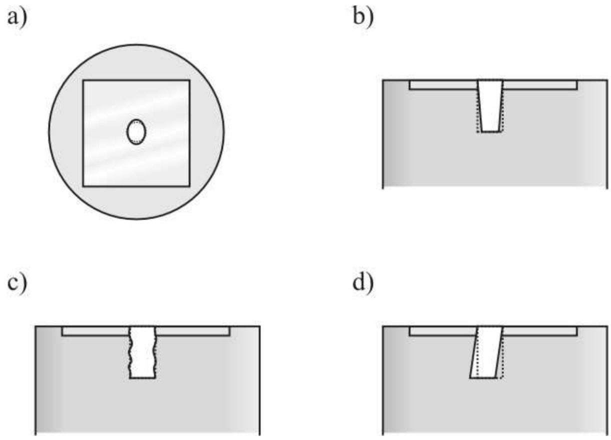


Fig. 1. Chosen examples of bush made errors and its fixing in the observation pillar's head
Rys. 1. Wybrane przykłady błędów wytworzenia tulei i jej montażu w głowicy słupa obserwacyjnego

Inclination of the observation pillars of the research networks , located in the Sudety Mts., were measured in few campaignes in the years of 1993 to 2003 [Cacoń et al. 1996, 2004, Jamroz 1997 and 2000], using clinometer [Cacoń and Ćmielewski 1992], see figure 2.

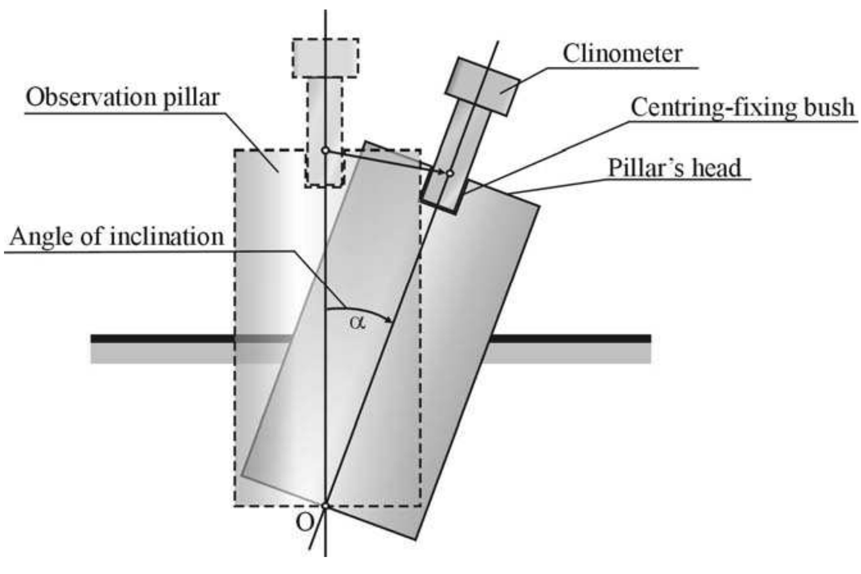


Fig. 2. Scheme of measurements of the pillar inclination using clinometer
Rys. 2. Schemat obserwacji pochylenia słupa z wykorzystaniem pochyłomierza

Results of the measurements as well as conclusions from the inclination observations and instrumental procedures inspired preparation of several variants of centring-fixing sub-assemblies as well as measure modules of clinometers.

## 2. CENTRING – FIXING MODULES OF CLINOMETERS

During the pillar inclination investigations in the local gravity field, the most important element is precise fitting of the clinometer in the centring bush axis. Due to that, the first step of the measurement procedure is determination of the axis by centring-fixing sub-assembly. The above unconveniences connected with shape and errors of processing and bush fixing were the reason of preparation the following variants of centring-fixing sub-assembly of the clinometer:

- double plate
- multi roller
- multiconical
- bush-conical
- roller-eccentric

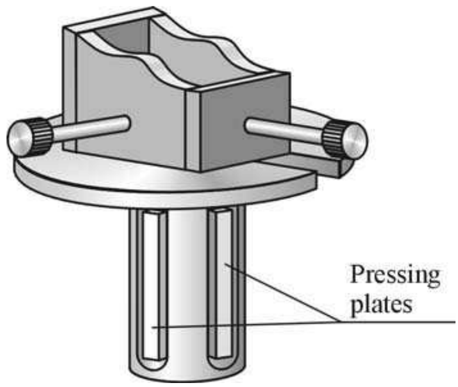


Fig. 3. Double plate centring-fixing sub-assembly of the clinometer
Rys. 3. Dwupłytkowy podzespół centrująco-mocujący pochyłomierza

During measurements using clinometer with the module presented in figure 3, we can achieve better stability and centring of the instrument. It is realized by independent regulation of pressure of each plate against the inner bush surface.

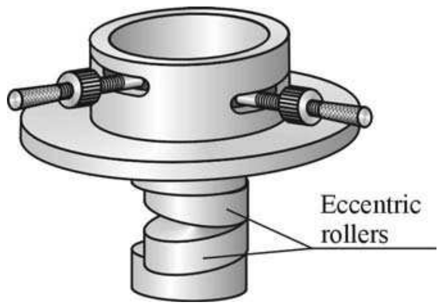


Fig. 4. Multi roller centring-fixing module of clinometer
Rys. 4. Wielowałeczkowy podzespół centrująco-mocujący pochyłomierza

In the module presented in the figure 4, stability and centring of clinometer in the pillar bush is achieved by eccentric aberration of discs unit on various levels of the bush, minimalizing lack of the precision during bush producing.

Figure 5 presents multiconical module which allows fitting its axis into the bush in several levels. Thanks to this, influence of ovalness and local walls deformation on results of the measurements is minimalized.

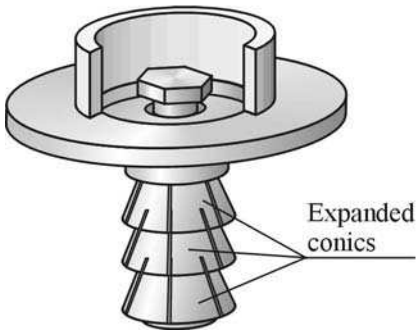


Fig. 5. Multiconical centring-fixing module of clinometer
Rys. 5. Wielostożkowy podzespół centrująco-mocujący pochyłomierza

Figure 6 presents bush-conical sub-assembly. Its construction should allow to minimalize negative affects of conicalness and local deformation of the bush wall, as well.

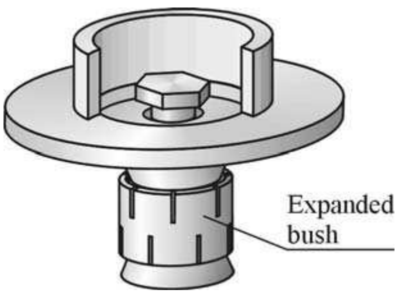


Fig. 6. Bush-conical centring-fixing sub-assembly of clinometer
Rys. 6. Stożkowo-tulejowy podzespół centrująco-mocujący pochyłomierza

Roller-eccentric module, presented in figure 7, should allow stable centring, independently on ovalness of the bush.

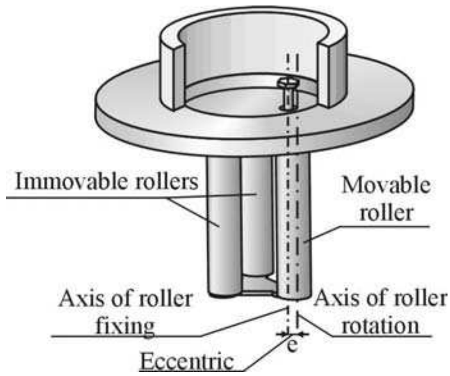


Fig. 7. Roller-eccentric centring-fixing module of clinometer
Rys. 7. Wałeczkowo-mimośrodowy podzespół centrująco-mocujący pochyłomierza

## 3. VARIANTS OF CLINOMETERS MEASURING MODULES

After the centring and fixing of the clinometer in the bush, some observations are conducted, determining the bush axis inclination angle in relation to local vertical line. The following variants of clinometer measuring modules were designed:

- fiber optical
- laser-prismatic
- laser-mirror

In the measurements campaignes in the area of Lower Silesia and in the Czech Part of the Sudety Mts., the clinometer with mono plate module was used (figures 8 and 9).

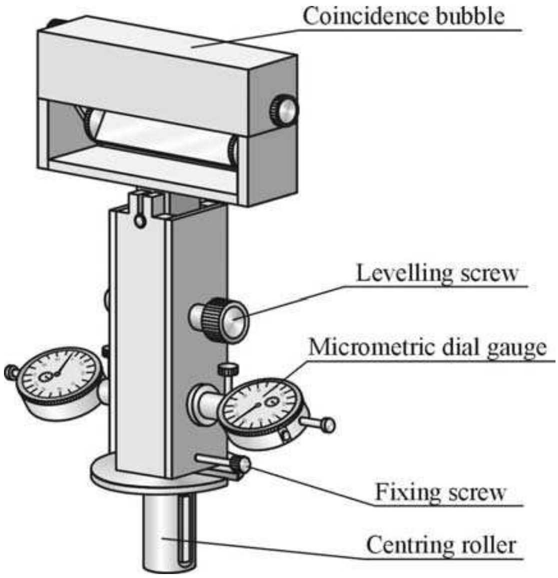


Fig. 8. Clinometer by Cacoń and Ćmielewski [1992]
Rys. 8. Pochyłomierz nasadkowy według Caconia i Ćmielewskiego [1992]

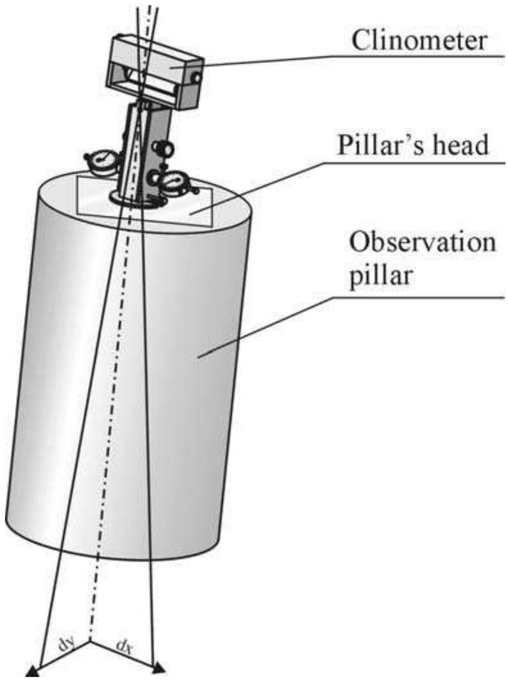


Fig. 9. Clinometer during the pillar inclination measurements [Jamroz 1997]
Rys. 9. Pochyłomierz nasadkowy w trakcie pomiaru pochylenia słupa obserwacyjnego [Jamroz 1997]

Development of fiber optical technology and miniaturization its modules [Szustakowski 1992] allowed for modification of clinometer construction. In the figure 10 proposal of the fiber optical modification of clinometer is presented. In the measurement module micrometric dial gauges were replaced by micrometric light conductoral sight and microscope with shifted cross-wire.

Development of the optoelectronics [Booth and Hill 2001] and easier access to its elements gives an opportunity of utilization such clinometers in several both technics and science fields, particularly during the process of construction of instruments facilitating geodetic measurements. An example of such construction is module of laser-prismatic clinometer (fig. 11). This module during the measurements is positioned each time according to magnetic North of the Earth using compass.

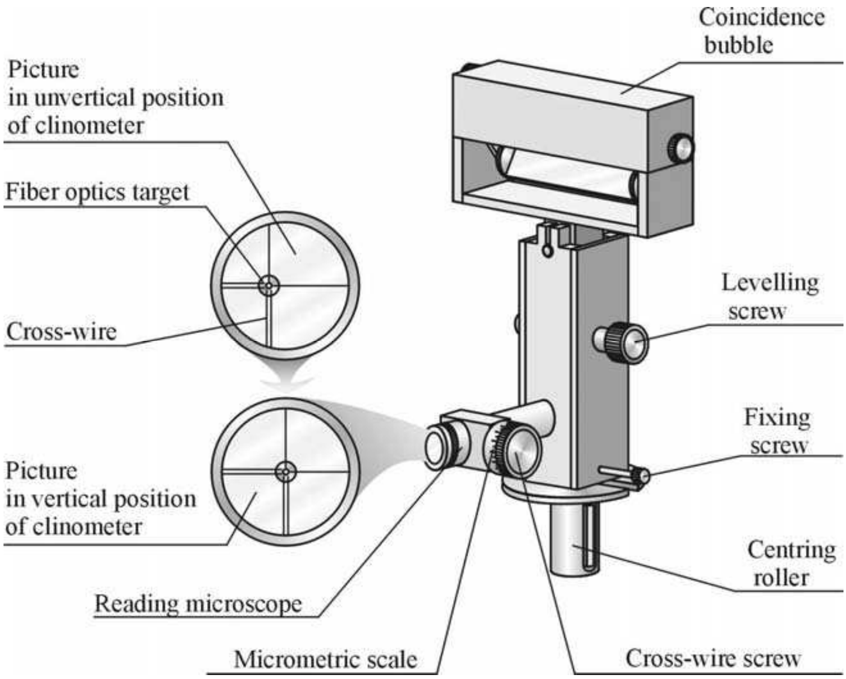


Fig. 10. Fiber optic clinometer
Rys. 10. Pochyłomierz światłowodowy

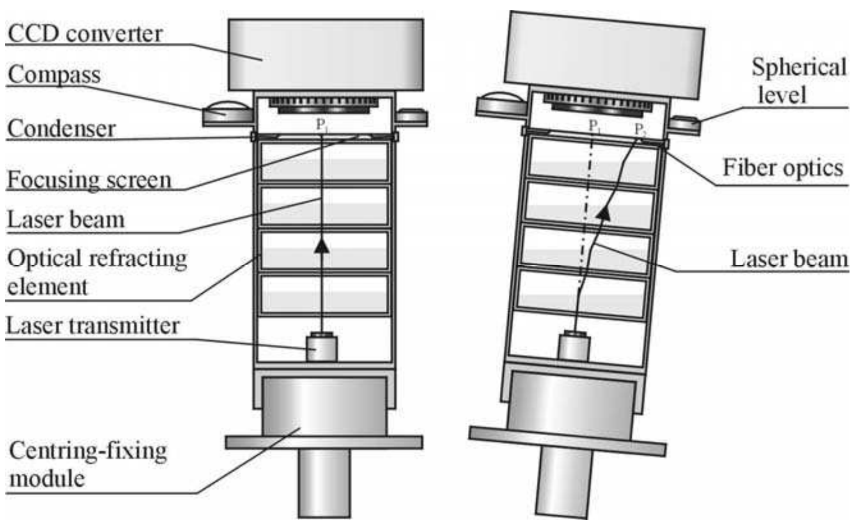


Fig. 11. Module of laser-prismatic clinometer
Rys. 11. Moduł pochyłomierza laserowo-klinowego

Pillar inclination is detected by the sub-assembly of the laser-prismatic clinometer. In the module a laser beam is deflected in several optical elements – liquid prisms of a variable breaking angle. Refracted laser beam is projected on the focusing screen equipped in four corners with light conductoral reference points (fig. 12) and then registered using CCD converter. Picture of the laser beam on the square focusing screen, in corners of which are luminous points (core front of fiber optic conductors), is analysed by computer (fig. 12). Measurement pillar inclination is the result of analyse. Measurements are oriented according to magnetic North by compass with a proper positioning of luminous points of the fiber optic conductors. Measurement range of the module of laser-prismatic clinometer and its observations accuracy are achieved by quantity and construction location of optical refracting elements.

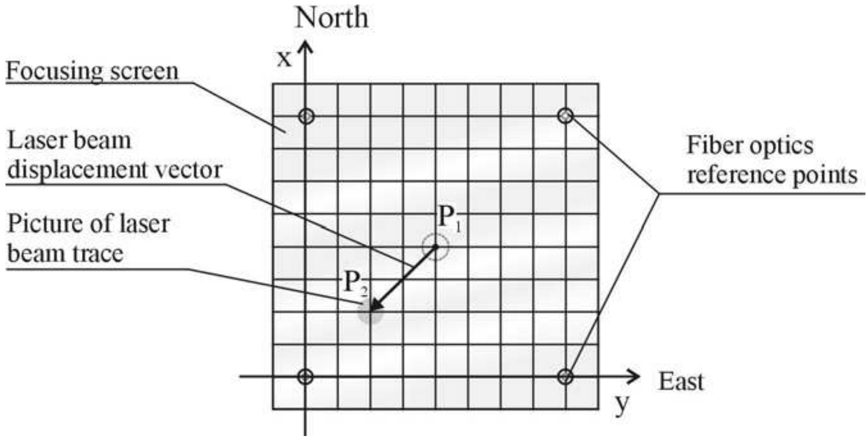


Fig. 12. Focusing screen with a picture of initial $P_1$ laser beam tracts established in the calibration process and actual $P_2$ during pillar inclination analysis

Rys. 12. Ekran-matówka z obrazami śladów wiązki laserowej wyjściowej $P_1$ ustalonej w procesie kalibracji oraz aktualnej $P_2$ w trakcie badania pochyleń słupa

Another proposal using optoelectronic elements is variant of the measurement module construction of the laser-mirror clinometer presented in figure 13.

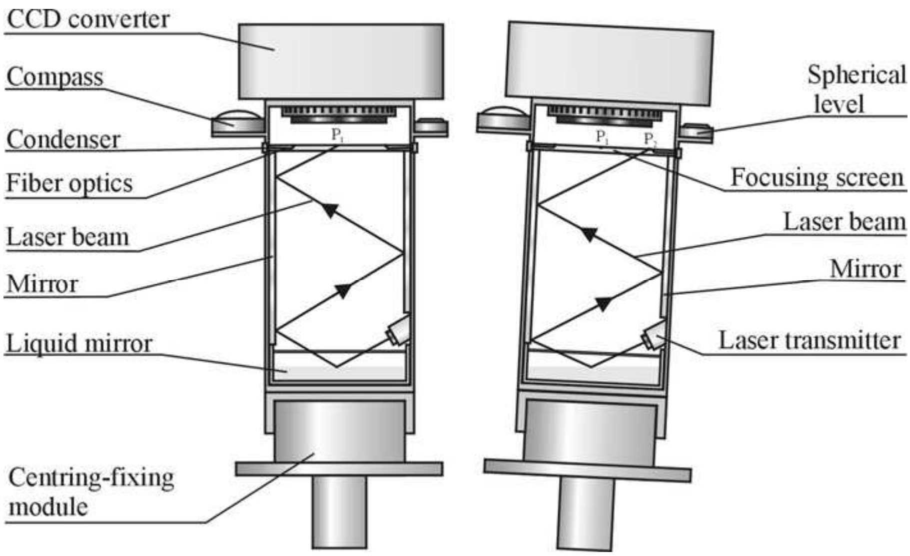


Fig. 13. Module of laser-mirror clinometer
Rys. 13. Moduł pochyłomierza laserowo-zwierciadlanego

In this construction laser beam is multiple reflected and reflection angles are functionally connected with position of laser–mirror clinometer module. When the pillar is inclinated a laser beam displaced in relation to vertical (initial) position on the focusing screen is registered by CCD converter. Next step is computer analysis which the goal to determine pillar inclination. Measurement range of the module of laser-mirror clinometer and its observations accuracy are achieved by construction location of laser transmitter (quantity of reflects).

In the presented constructions of laser clinometers it is possible to receive the pillar inclination in various directions.

## 4. CONCLUSIONS

Examples of the clinometers presented in the paper were prepared to observe self movements of network points (concrete pillars) and to receive data independent of relative deformation of single crustal blocks. These clinometers are not competitive for others geodetic intruments (GPS, Total-Station), but rather complementary for methods of objects deformation determinations. Presented variants of clinometers are the effect of improvement trial of geodetic measurements connected with determining pillars inclination when the pillar bushes are not precise. Construction of an example models of clinometer and its modules will allow to determine experimentally the measurement accuracy (test base calibration), as well as utility value, ergonomics and portativity of the instruments during exploitation.

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## PRZYKŁADY KONSTRUKCJI PRZYRZĄDÓW DO POMIARÓW POCHYLENIA SŁUPÓW OBSERWACYJNYCH (KLINOMETRÓW)

**Streszczenie:** W pracy przedstawiono warianty przyrządów służących do pomiarów pochylenia słupów obserwacyjnych. Zaprezentowane przykładowe konstrukcje przyrządów pomysłu autorów umożliwić mogą wyznaczanie kątowego i liniowego pochylenia słupów obserwacyjnych w sieciach geodynamicznych zlokalizowanych w Sudetach. Pozwala to na oszacowanie wielkości występujących ruchów własnych słupów i ich uwzględnienie w innych rodzajach pomiarów.

**Słowa kluczowe:** pomiary pochylenia, ruchy własne, klinometry, technologia światłowodowa i laserowa

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