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A motorized 5 m tape comparator for traceable measurements of tapes and rules

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ABSTRACT

A motorized 5 m tape comparator was constructed in TUBITAK UME for calibration of tapes and rules up to 5 m length in one set-up and further lengths in multiple set-ups. The system is a practical development and provides a cost effective solution for calibration of tapes in which the highest grade's accuracy requirement in OIML R35-1 e.g. is 600 µm for 5 m length and 1100 µm for 10 m length. It is mainly composed of 6 m rail system, mechanical parts, optical units and an integrated 6 m incremental linear encoder as a reference measurement axis for traceable measurements. The rails are kinematically located on a heavy marble construction and a motorized carriage, which employs a camera for probing of the scales on the tapes, is moved along the rails during the measurement. The image of the scale taken by the camera is viewed on the monitor screen together with the running software. The operator can perform the probing process by simply moving the carriage over the measured scales (tapes or rules) using a joystick. The carriage movement is measured by the incremental linear encoder previously calibrated by a laser interferometer and the software automatically takes the measurement results from the incremental linear encoder, applies correction values previously defined and determines the length of the tapes and rules as well as deviations from nominal lengths. The estimated expanded uncertainty of the steel tape measurement is $U = 54$ µm in one set-up (for 5 m length) and $U = 77$ µm in two set-ups (for 10 m length) at the confidence level of approximately 95%. Uncertainty budget for calibration of the device itself and for calibration of the test tapes are explained in detail. The results of extensive experimental work and analysis are provided by demonstrating application of science and technology of measurement and instrumentation. Investigations for long term stability of the system are given with the reported test results for the years of 2003-2011 and participated intercomparison results to validate the device scientifically are illustrated.

1. Introduction

Line standards such as measuring tapes and rules still form a major component in the traceability chain for dimensional metrology particularly in legal metrology, in surveying applications and engineering workshops. The calibration or verification of these standards is carried out in order to check whether they comply with the classes given in OIML recommendations [1] or with the user specifications. OIML R35 series [1] give set of recommendations for the type evaluation and initial verification testing of material measures of length for general use as well as the specifications of the classes. European standards and directives of 73/362/EEC specify the accuracy classes of the tapes for European market [2]. Recently, ASME B89.1.7 'Performance standard for steel measuring tapes' has been launched as a draft document to give guidance about

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calibration of steel measuring tapes [3]. According to all above standards, traceability has to be assured usually through a reference measurement tape in which a reference and a test tape are stretched side by side and the length of the test tape is determined in terms of the reference tape. This method is called as comparison method and requires calibrated reference tapes or rules traceable to SI unit of length. Therefore, absolute length measurement of the reference standards is necessary.

In the former times, the reference tape used to be compared with 1 m national line standard at each metre [4]. With the development of lasers, absolute calibration systems using a precision guide rail and laser interferometer were developed [5–11] to provide traceability directly through stabilized lasers. A steel tape comparison, EUROMET.L-S14 was performed in order to check the capability of National Metrology Institutes (NMIs) in Europe for calibration of tapes. 14 NMIs out of 16 participants used laser interferometers as Ref. [12]. Capabilities of NMIs worldwide with detailed information and the uncertainties ranging from about 10–100 μm (for the length independent part) can be obtained from CMC (Calibration Measurement Capabilities) data base of the BIPM (Bureau International des Poids et Mesures) [13].

The comparison or absolute calibration method may be applied to the workshop rules (no stretching) and tapes of OIML R35-1 Class I (trade measures) up to Class III [1] depending on the accuracy requirements. The accuracies in OIML recommendations start from $(0.1 + 0.1 \times L)$ mm to $(0.6 + 0.4 \times L)$ mm (L is the length in meters). The tapes are normally quoted as standard at a specified temperature and tension.

Most of the National Metrology Institutes (NMIs) designed and manufactured their own equipment for calibration of tapes and rules using laser interferometers. Detailed information about such devices is given in EUROMET.L-S14 final report [12]. The maximum length of the designed equipment in the first place depends on available laboratory size. Smaller size measurement devices can also used. Larger tapes can be measured in several intervals and the measurement results are connected and reported with higher uncertainties.

A bench for measurement of tapes and rules up to 5 m in one set-up and further lengths in multiple set-ups has been designed and manufactured in TUBITAK UME [10]. The measurement system is designed that length measurement can be performed by a linear encoder as well as by a laser interferometer. The purpose of using the linear encoder with 0.1 μm resolution is to reduce the cost for length measurement system. This was achieved by 5 tape comparator of TUBITAK UME and 30,000 USD cost of laser interferometer is reduced to 5000 USD by using the linear encoder as a measurement system. The linear encoder is calibrated by the laser interferometer and the traceability of the measurement is assured. The laser interferometer can also be used for tape and rule calibration optionally with the system. However, it is usually reserved in the laboratory for other calibration purposes.

Later, the device has been modified by adding a motorized driving system in order to reduce the work load of the operator and has been used in the intercomparison EUROMET.L-S17 to check its capability. The paper describes the motorized 5 m tape comparator with detailed calibration procedure using a laser interferometer and reports uncertainty budget for the calibration of device itself and then calibration of test tapes and rules. Investigations for the performance of the device between 2003–2011 are reported and the results are compared with the accuracy values specified in OIML recommendations.

The work is considered that it is a practical development and provides a cost effective solution for calibration of tapes in which the highest grade's accuracy requirements are starting from 200 μm constant value. The extensive experimental work and analysis accompanied with uncertainty budgets in the paper will provide the readers with a good demonstration for application of science and technology of measurement and instrumentation ranging from obtaining traceability to validation of the system according to requirements.

2. A motorized 5 m tape comparator

General view of 5 m tape comparator is illustrated in Fig. 1. The system is located in the dimensional laboratory, the temperature specification of which is 20 0.5 °C. It is 6.6 m long, 0.6 m wide and 1.5 m high. The comparator mainly consists of base construction, 6 m rail system, 6 m incremental linear encoder (as a reference measurement axis), mechanical parts and optical units.

2.1. Base and rail system

The base made of marble blocks is supported on 3 steel frames interconnected to each other and rest on the steel spheres located on the adjustable screw mechanism. Two rails made of 6 m length of centreless ground steel rod (about 25 mm in diameter) are spaced 360 mm apart and are supported in adjustment mechanisms positioned every 600 mm which enables vertical and lateral adjustment of the rails. The rails have been adjusted during construction so that the straightness of the system is that a fixed point

Fig. 1. General view of UME motorized 5 m tape comparator.