Journal of Electrostatics 82 (2016) 17–21

Contents lists available at ScienceDirect

Journal of Electrostatics

journal homepage: www.elsevier.com/locate/elstat

Accurate AC/DC voltage measurements using electrostatic comparator

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ARTICLE INFO

Article history:
Received 17 February 2016
Received in revised form
5 April 2016
Accepted 24 April 2016

Keywords:
Electrostatic
Voltage comparator
Electrode
Voltage measurement
Electrostatic transducer
Photoelectric transducer

ABSTRACT

The electrostatic AC-DC voltage comparator for precise voltage measurement in voltage range of 100–1000 V and frequency range of 20–100,000 Hz was designed. The equality of AC and DC voltages transforms into horizontal positioning of the beam, which is registered by two photoelectric transducers. DC voltage was measured by voltage divider, standard cell and low-voltage comparator. The construction, main characteristics, and sources of errors are described. The comparison error has been determined as having the value of 0.003% at the voltage of 100 V and the value of 0.0009% at the voltage of 1000 V.

1. Introduction

All precise measurements of AC voltage are accomplished with Thermoelectric Voltage Comparators (TVCs). There are two main reasons to use TVCs: high precision and high manufacturability of a TVC. Undoubtedly we can only speak of true and validated measurement results when we can validate the results by other independent measuring methods. Electrostatic AC-DC Voltage Comparator (EVC) can be used for validation of voltage measurements obtained by TVCs [1].

Some special designs of electromechanical balances allow for the precise measurement of electromagnetic and non-electromagnetic values, such as voltage, current, power or mass in standards laboratories [2,3]. For measuring high AC voltages seems suitable to use electrostatic balance, which is an electrostatic AC-DC voltage comparator [4]. The equality of AC and DC voltages transforms into horizontal positioning of the beam which is registered by two photoelectric transducers. DC voltage is measured by DC voltage divider [5], standard cell and low-voltage comparator.

The advantage of electrostatic measurement units is that they can be used for measurement of effective values of voltage in wide frequency range and they don't require AC voltage dividers. On the other hand electrostatic measurement units have a few fundamental limitations that negatively affect their precision [6,7].

The main limiting factor of EVC is its low sensitivity [7]. The increase of accuracy of EVC by traditional methods meets some difficulties which are defined by weak rotating moment and high sensitivity to vibrations. Those difficulties were minimized in the design of described EVC.

The designed electrostatic AC-DC voltage comparator is intended for the precise measurements of AC voltage in voltage range of 100–1000 V and frequency range of 20–100,000 Hz in standards laboratories of a higher tier.

2. Construction

The construction diagram of EVC is shown on Fig. 1.

The construction of EVC includes the horizontal beam B with attached movable electrodes LVE1 and LVE2. The fixed electrodes HVE1 and HVE2 are fastened to isolators IS found on the comparator base of EVC. The electrostatic transducer A consists of electrodes LVE1 and HVE1, and the electrostatic transducer B consists of electrodes LVE2 and HVE2.

For detection of the deflection of moving part of EVC two photoelectric transducers (FET) have been used. One FET consists of the light source, the condenser C, flag F with slots attached to the end of the EVC beam and differential photoresistor PR. When the beam is in the equilibrium the illumination of two parts of PR is equal and the pointer of null-indicator is in zero position. When the beam moves from the equilibrium PR are lighted differently and deviation

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http://dx.doi.org/10.1016/j.elstat.2016.04.005

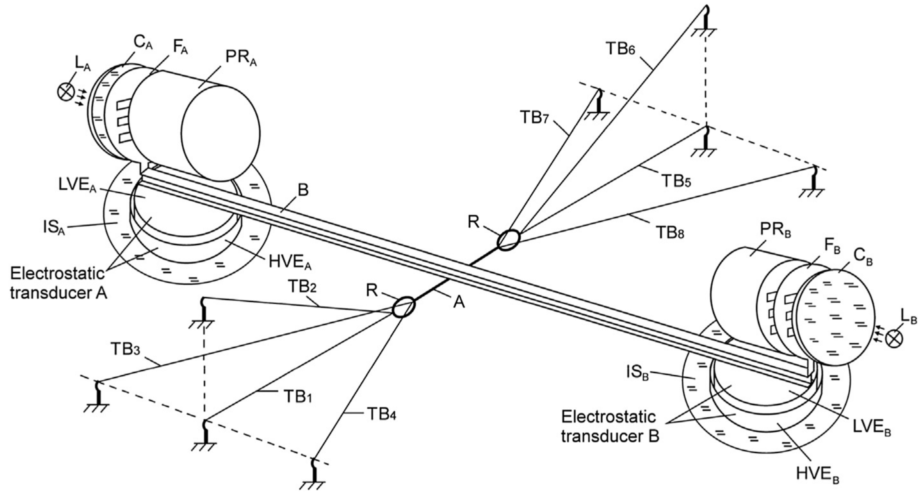

Fig. 1. The construction diagram of EVC.

of the pointer of the null-indicator is proportional to the deviation of the beam.

Two FETs, situated at the ends of the beam, are connected serially and their output signals are summed up. Also, the way the photoelectric transducers are connected provides that vertical vibrations of the movable part causes their output signals to suppress each other, while rotation of the movable part causes their output signals to sum up. Such connection of PRs allows increasing the sensitivity of EVC and it significantly decreases the influence of vibration.

The construction of electrostatic transducer (sectional view) is shown on Fig. 2.

The construction includes a multi-stage cylindrical high-voltage electrode HVE and a low-voltage electrode LVE, a tuning electrode TE, a handle of tuning electrode HTE, a high-voltage contact HVC and an isolator IS, fastened on comparator base CB. The tuning electrode TE is situated in the center of the fixed electrode HVE and moves up or down by rotation of the HTE. That movement changes the capacitance C_{tun} between TE and LVE that changes the common capacity of electrostatic transducer. The TE is intended for the continuous adjustments of capacitance of electrostatic transducers for achieving the identical counteracting moments generated by applied AC and DC voltages. The identical values of the capacitance of the electrostatic transducers are verified by the null-indicator.

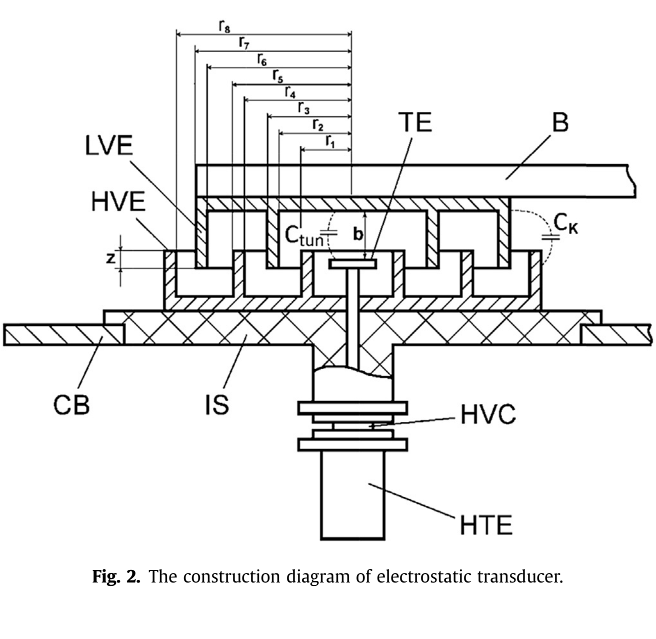

Fig. 2. The construction diagram of electrostatic transducer.

One of the main reasons that prevent obtaining the high precision measurements using EVC relates to its counter torque: the suspensions of the moving element add additional counter force moment which decreases the sensitivity of EVC. What makes the problem worse is the long thin suspension elements required for higher sensitivity of EVC. They are very vulnerable to mechanical vibrations.

The problem of the design of EVC with high sensitivity and mechanical interference immunity has been solved by introducing a structure made of eight long tout bands TB_1-TB_8.

Suspension of the moving part operates in the following manner. When the measuring voltage is applied to the electrostatic transducer, its moving part deviates from the starting position. The mechanical counter-force moment is the result of the action of four tout bands so that the total counter force moment is four times stronger than a moment created by single tout band. The tout bands are set in a sharp angle to the beam axis of rotation and that helps reducing vibrations of the moving part. To further reduce vibrations the ends of taut bands are attached to the cushioning springs. There are no factors restricting the length of taut bands and it is beneficial to make them as long as possible. The longer they are the weaker the total counter-force moment is, as well as the residual deformation of taut bands, and, hence, the higher the sensitivity of the EVC becomes.

Proposed approach to construction of the moving part suspension of the electrostatic voltage comparator allows deployment of the multi-stage cylindrical movable and fixed electrodes of the electrostatic transducers.

The torque and counteracting moments cancel each other when the beam is in the horizontal position affected by both the measured AC voltage and equivalent DC voltage:

$$M_A = M_B, \tag{1}$$

where M_A and M_B are counteracting moments, generated by AC and DC voltages applied to the electrostatic transducers A and B, respectively.

The equivalence of the moments is reached by adjusting DC voltage. It is detected by zero deflection of null-indicator pointer. The DC voltage reached at the moment of compensation is equal to the measured AC voltage. Voltages U_A and U_B applied to the