AIR ION COUNTERS AND SPECTROMETERS DESIGNED IN TARTU UNIVERSITY

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Counters

Air ion counters are used for measuring the concentrations of air ions in atmospheric physics research as well as for various applications of air electricity in medicine, industry etc. Air Electricity Laboratory of Tartu University has a long experience in the design and use of various air ion counters. The paper presents a short survey of the design of the counters.

The first counter designed and built in Tartu University was a stationary integral counter with a mechanical electrometer for the measurement of small and large air ions. The counter was built in university workshops by engineer A. Susi under the supervision of J. Reinet in 1950 [1]. In the end of the 1950s this counter was substantially developed by O. Saks who applied a vibrating reed electrometer for the measurement of low currents [2]. In the 1950s and at the beginning of the 1960s several portable integral air ion counters with a mechanical electrometer (model *SG-2M*) were designed [3].

In 1963 J. Salm designed the first portable integral counter with a vibrating reed electrometer [4]. Theoretical research connected with the design of air ion counters was started in 1956 by H.Tammet [5]. Development of portable air ion counters of the series *SAI-TGU* was started under his supervision in 1964 [5,6,7]. Universality and high sensitivity of these counters were achieved by the use of a vibrating reed electrometer. The counters were equipped with a measuring capacitor which took into account and minimized such distorting factors as turbulence, edge effect, and ion adsorption in the inlet device. The counters *SAI-TGU-66* were produced for about fifty research institutions in the Soviet Union and Eastern Europe.

In 1960-1980 research in air ion applications was highly active. This motivated the design of new air ion counters, whereas the increase of reliability was considered as the main aim of improvements. Several counters were designed according to special requirements. The examples are the counter *UT-7001* with a small-size probe-like measuring capacitor and a low-inertia counter *UT-7004* with a measuring capacitor working at high pressures (up to 5 atm.)

With the air ion counter *UT-6914* an attempt was made to create a highly reliable device suitable for industrial production. In this counter, and later in *UT-7406*, ventilation of the inner volume with dried air while maintaining a low superpressure in the inside of the case was used [8]. An attempt was made to improve the electrometric commutator of the measurement ranges. In the counter *UT-6914* a needle switch was used, however, its design turned out to be unreliable. In the later developments *UT-7406* and *UT-7714* commercially manufactured magnetically controlled "hercon" contacts were used. They were abandoned due to the poor insulation properties of the glass shell, as even insignificant contamination brought about a large bias current.

Up to 1977 the laboratory-made dynamic capacitors [10] were used in all counters. The commercially made dynamic capacitor *DRK-3* was introduced only in the last counter of Tartu University *UT-7714* designed with the vibrating reed electrometer. The other improvements of this counter were a digital display and output to an automatic data acquisition system.

After 1977 solid state electrometric amplifiers were used in all new counters. This was facilitated by the appearance of new MOS-transistors with low bias currents. Due to the introduction of MOS-electrometers the design of counters was significantly simplified. In the case of selected MOS-transistors *KP-305* the guaranteed bias current is about 10^{-15} A. A necessary stability of zero level is ensured by thermo-compensatory elements of the circuit and by the use of the transistor near the thermo-stable point [11]. The first counters with MOS-electrometers were *UT-7905* and *UT-8217*.

The next model in the family of Tartu University air ion counters is *UT-8401*, designed to meet high technical requirements including maximum reliability, easy operability, minimum size and weight. The inner volume of the device is ventilated with dried air, a superpressure of 10-20 mm water column is maintained in it. The insulator of the measuring capacitor is protected by ventilation with dried air. Improvements are made in the commutation of measurement range and in switching on/off of the operation mode. A built-in flow-chart recorder or a pointer instrument is available as indicator.

The main parameters of *UT-8401* are as follows.

1. The limiting mobility from $3.2 \cdot 10^{-4}$ to 2 $cm^2/(V \cdot s)$.
2. The range of concentration from 10^2 to $6.4 \cdot 10^8$ e/cm^3.
3. The size of the counter 250 x 335 x 525 mm.
4. The weight depending on the type of built-in recorder is 12-16 kg.
5. The power consumption is below 50 W.

The counter *UT-8401* was produced for over a hundred institutions in the Soviet Union.

All the above counters are designed to measure both small and large air ions. If to give up the measurement of large air ions, the design of the counter will be essentially simpler. Such counters will be described below. They are designed to indicate small air ion concentration and/or electrical conductivity of air, because the technical requirements at the measurement of small air ion concentration and air conductivity are identical.

Building and testing of an aspirational air conductivity measurement device with a modulating measuring capacitor was completed in 1980 [12]. Such a measuring capacitor is especially reliable in field conditions as its main insulator is not sensitive to humidity and contamination. Requirements set to the electrometric amplifier are relatively lax and there is no need for zero adjustment. One conductivity meter on such a principle was built in 1984 by the order of the Institute of Experimental Meteorology of the Soviet Committee of Hydrometeorology and for a long time it has been used for field measurements.

About 1980 a reliable conductivity meter making it possible to estimate also the concentrations of small air ions was built for a workshop of physics students [13].

F. Miller introduced an original measuring capacitor with an inner collector electrode and an electrometer inside the electrode [14]. The whole system requires only one high-ohmic insulator which can be optimized from the electrometric point of view and is sufficiently protected from pollution. The device consists of separate measurement and ventilation blocks. The measurement block consists of two measuring capacitors and a power source. The device makes possible simultaneous measurement of positive and negative conductivity. The size is 180 x 150 x 340 (measurement block) and 150 x 180 x 200 mm (ventilation block). The total weight is less than 9 kg.

A small-size air ion meter for the measurement of air conductivity *UT-8510* was designed by H. Tammet [15]. The device is meant for conductivity measurements in the range 1-1000 fS/m and has an original construction of the sensor with a plane collector electrode. Automatic zero correction is used for the suppression of measurement errors. The air ion meter has a modular construction and consists of three blocks: sensor, fan, and controller. The modular principle makes it possible to use different sets of equipment, whereas the universal air ion sensor is not modified. The size of the sensor is 160 x 100 x 23 mm, weight 0.27 kg.

The latest development is a small air ion meter *UT-9007* with a digital display and remote control. The limiting mobility of the device is 0.5 $cm^2/(V \cdot s)$. The measuring capacitor and the electrometer of the air ion meter are similar to the construction described in [12]. The limits of the measurement of air ion concentrations are from 10 to $2 \cdot 10^5$ e/cm^3.

Spectrometers

In general air ion spectrometers are similar to air ion counters but they are specially adapted for getting more detailed information about the mobility spectrum of air ions. Therefore, as a rule, they also have a more complicated structure than the counters. All the ion spectrometers use a static or quasistatic electric field as a basic factor for air ion classification. They can be divided into two large groups: spectrometers with motionless (still) air called drift tubes [16] and spectrometers with flowing air (aspiration spectrometers) [5]. The choice of a drift tube is reasonable when:

- the volume of air under investigation is limited,
- there are only small ions to be measured,
- the concentration of air ions is sufficiently high.

The choice of an aspiration spectrometer, in its turn, is reasonable when the volume of air is not limited. Aspiration spectrometers can be used in the case of low air ion concentration and there are no limitations with regard to the region of mobilities.

Air Electricity Laboratory of Tartu University has a long experience in the study, design, and use of aspiration spectrometers. The basic principles of mobility spectrometry have been published in the monograph [5]. Later the principle of multichannel spectrometry has been elaborated, the problems of resolution have been specified, the automation of operation and digital data processing have been introduced.

The first multichannel automatic air ion spectrometer (model *UT-7205*) was built in 1972 [17]. This spectrometer was designed on a parallel principle: all the spectral intervals in a wide mobility range were measured simultaneously. The spectrometer has two independent measuring capacitors, the outer cover of either is divided into 25 well insulated measuring electrodes. Adjusting properly the regime of operation, it is possible to measure the mobility spectrum simultaneously as maximum in 50 intervals which can cover up to three orders of magnitude of mobility. Using various regimes it is possible to expand the range from 0.0001 to 3.2 $cm^2/(V \cdot s)$. The spectrometer has a built-in automatic control unit: one has to choose the desirable regime on the keyboard and to push the starter button. After the selected measurement period the device puts out the measurement data on a punched tape, ready to be fed into a computer.

The shortcomings of the described spectrometer were mainly of technological origin and resulted often in technical failures of the instrument.

The further development of that same spectrometer was influenced by the problem of electrical analysis of aerosols. A special charging chamber for aerosols was joined with the intake of the spectrometer [18]. This chamber enabled to give definite charges to aerosol particles by means of an unipolar corona discharge. The mobility spectrum of the particles charged in this way was measured by means of the above spectrometer and after that the size spectrum of aerosol particles was calculated on the ground of the mobility spectrum. Further development of this principle resulted in the design of a special multichannel electrical aerosol spectrometer [19]. Aerosol spectrometry was established as a separate field of research in laboratory and it is not considered in the present paper.

The further development of air ion mobility spectrometers continued with the design of the multichannel spectrometer *UT-7914*. The control unit of this spectrometer was designed in a modern engineering level. The basic technical characteristics of the spectrometer *UT-7914* are as follows:

- mobility range 0.00048-0.48 $cm^2/(V \cdot s)$ is logarithmically divided into 9 main intervals and a supplementary interval 0.48-∞ $cm^2/(V \cdot s)$ provided for small ions;
- the spectrometer has two measuring capacitors each of them with 5 measuring electrodes; one capacitor is fitted for measurement of more mobile and the other for measurement of less mobile air ions;
- each measuring electrode is connected with an individual small-sized MOS-electrometer [11]. Such an electrometer in the structure of the spectrometer guarantees the measurement of concentrations of air ions beginning from about 10 cm^{-3} in intermediate ions mobility intervals and from 50 cm^{-3} in large ions mobility intervals.

The design of the spectrometer *UT-7914* was accomplished in 1987. Special preliminary capacitors for the realization of second-order apparatus differentiation have been installed on the intakes of the measuring capacitors [21]. In 1988 the spectrometer has been put into a continuous exploitation in the Air Ion Observatory Tahkuse.

An interest in the detailed study of the mobility spectrum of small air ions in natural conditions occasioned the design and building of a six-channel air ion spectrometer (model *UT-8415*) [22]. The measuring capacitor has a divided air flow and six outer measuring electrodes. By switching the voltage it is possible to measure mobility spectra in 10 logarithmically distributed mobility intervals in the range 0.32-3.16 $cm^2/(V \cdot s)$. The measurement of the mobility spectra at both polarities in this range takes as minimum a period of 5 min.

A particular class of spectrometers is represented by scanning-voltage one-channel air ion spectrometers, which are provided for investigations of the effect of chemical microadmixtures on mobility spectrum. The first spectrometer of this class (model *UT-7509*) was built in 1975 [23]. This spectrometer is equipped with a corona point for unipolar ionization of the air under investigation. The air flow passes the corona point, runs through a coaxial electrofilter and enters the measuring capacitor, which has one narrow (outer) measuring electrode. By scanning the voltage the mobility range 0.6-2.4 $cm^2/(V \cdot s)$ is run through in 75 s.

The next spectrometer of this class (model *UT-7801*) was finished in 1978. This spectrometer is similar to the above model *UT-7509*, but an extra effort has been made to raise the spectral resolution [24,25]. The invention [26] was used to avoid the errors due to the incomplete sedimentation of air ions in the entrance filter.

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