UDC 625.712.2 (045)

Julij Kryvenko

REMOTE WAYS TO CONTROL WATER DEPTH ON THE RUNWAY SURFACES

The National Aviation University
E-mail: krivenko.yuliy@yandex.ua

Abstract. *In the article are provided the findings on the water draining from the runway surface obtained with the use of an automatic remote water depth sensor. The results obtained enable improvement of water depth control, increase safety, and aerodrome capacity.*

Keywords: friction coefficient; safety, runway; water depth sensor; water draining.

1. Introduction

The take-off and landing manoeuvre safety which belong to the complex stages of a flight depend largely on the timely and objective control of runway (RWY) pavement surface. The surface conditions can be assessed visually, by way of measurement of friction coefficient between a special purpose wheel and the surface (K_{fr})[1], and amount of atmospheric precipitation on the runway pavement.

The existing control method [1-3] has a number of shortcomings for it requires periodic closure of runway to serve flights. The scheduled engagement of the aerodrome service vehicles depends on the flying rate and shall be accomplished not less than twice per a day. On pavement surface conditions change one should carry out unscheduled engagement of vehicles that leads to rise in runway maintenance costs and aerodrome capacity reduction. Meanwhile, there are no automatic, and particularly, remote methods to measure the precipitation depth, and one has to do it manually. The weakness of the current control method also lies in the fact that the data obtained are valid only at the moment of measurement and may not reflect the actual state of pavement should any atmospheric changes occur.

2. Analysis of the latest research and publications

In Kyiv the employees of the National Aviation University of Ukraine conducted a long-term research to develop a system of remote automatic control of water depth on the surface of RWY. When performing research in laboratory settings and two RWYs — the one of which is in *Kyiv-Zhuliany Airport* and 1,800 m long and another one is in *Mineralnye Vody Airport* and 3,900 m long — they used automatic remote water depth sensors, the so called *FAP sensors*, developed at the Faculty of Airports of the National Aviation University (NAU) (Picture 1) [4,5]. The key principle of sensor operation is hydrostatic. This device can withstand freezing temperatures. The sensor is also equipped with electrodes to determine the surface humidity, availability of chemical agents and automatic system start-ups and shut-downs.

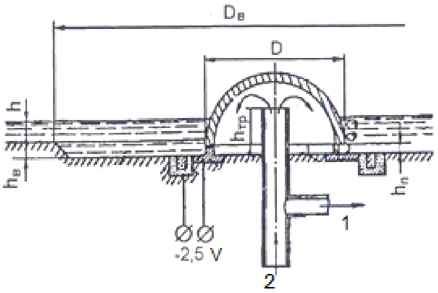


Fig. 1. Water depth sensor designed for runways, the so called *FAP sensor:* 1 – from the compressor; 2 – to the differential pressure gauge

The sensor was approved by the state metrological certification authority and accepted as a working measuring device for RWYs within the accuracy of 0.4 mm. The connection of the sensor (Figure 2) is made to a standard differential pressure gauge with a small head difference of 160-200 Pa.

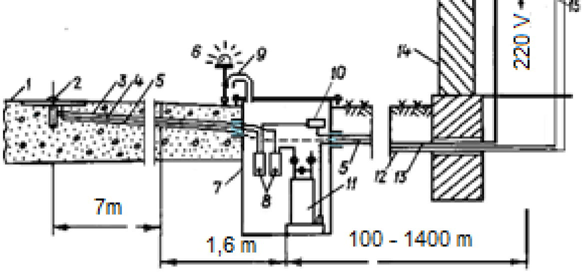


Fig. 2. Sensor and devices during research at the aerodrome

---

[1] Note: Measurements K_{fr} using the fifth wheel of the aerodrome service vehicle or the wheel of the pulling trolley can only simulate the actual aircraft's tire grip at the moment of taking off or landing.

Figure 2 also displays: *1* – RWY surface; *2* – water depth sensor; *3*,4– pressure tubes from microcompressor and towards primary device of differential pressure gauge; *5* – cable from signalling-and-actuating device towards the sensor's electrodes; *6* – landing system light; *7* – chamber to protect microcompressor and differential pressure gauge; *8* – condensate tanks; *9* – atmospheric pressure feed; *10* – microcompressor; *11* – primary device of differential pressure gauge; *12* – cable to connect the primary and secondary devices of the differential pressure gauge; *13* – microcompressor power supply; *14* – landing system control unit; *15* – signalling-and-actuating device; *16* – secondary device of atmospheric pressure gauge or analog-to-digital converter and the computer.

Specific results for automatic measurement of water depth on the RWY in rainy weather are provided in Figure 3 (1, 2 and 3 are the short-, mean- and long-duration rainfalls).

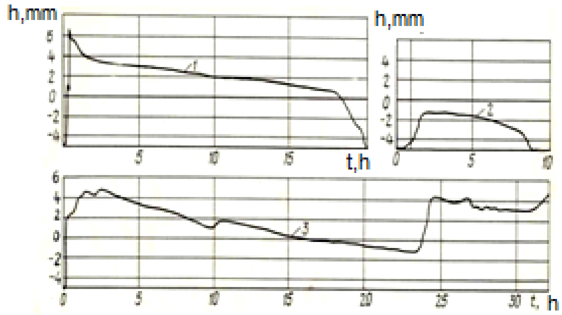


Fig. 3. Typical measurement results for water depth on the RWY in rainy weather in regard to *Kyiv* airport.

The first thing one should pay attention to is the stability of water depth on the pavement compared to the rainfall intensity variation (Fig. 4). Fluctuations in atmospheric processes make rainfalls unstable to a more considerable extent, particularly the ones with strong intensity when water depths on the RWY can reach high levels. On the contrary, the pavement surface accumulates precipitation and stabilises flows due to the significant resistance to water flow, enabling remote control of water depths on the whole surface of the RWY.

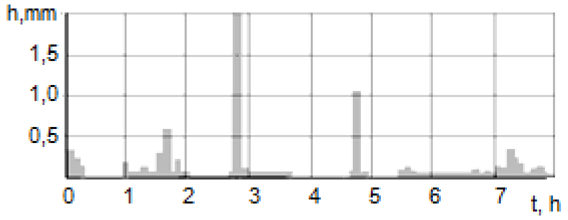
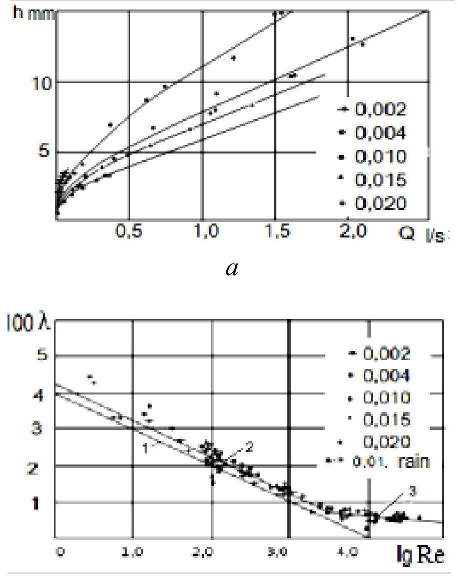


Fig. 4. Rainfall diagram typical for European and American plains

In addition to the testing of sensors in the lab settings and in actual practice (on the RWY) which demonstrated their high quality, the research performed allowed to reveal a number of properties pertaining to water flows on the RWY surface [6-8].

The analysis of the findings obtained demonstrated that the actual depth values on the runway exceed significantly the depths which can be expected on the basis of the known dependencies discovered by R. Manning or academician M.M. Pavlovskyi and provided in the regulatory documents [9,10].

Figure 5-a exemplifies the laboratory findings obtained on the smooth concrete surface presented as the dependencies of water depth h from water flow *Q* under various surface slopes, and Figure 5-b illustrates the dependency of flow resistance coefficient λ from the flow mode – from the Reynolds number.



a

b

Fig. 5. Dependencies of flow depth *h* from water flow *Q* on the concrete surface (a) and resistance coefficient λ from the flow mode - from the Reynolds number (b). The flow bed slope values are indicated by the dots.

The research was performed using a 280 mm wide and 4 m long tray, with flow depths ranging from 0.2 to 20 mm and slopes within the ranges of 0.002-0.02.

Flow resistance coefficient λ was defined using the Darcy–Weisbach equation –

$$\lambda = 8ghi/ V^2,$$

and the Reynolds number was defined using the equation for the plane flow –

$$\mathrm{Re} = 4Vh/\nu,$$

where i is the surface slope, V is flow velocity, ν is kinematic viscosity coefficient, and g is gravitational acceleration.

In Figure 5-b the line 1 illustrates the dependency which corresponds to the ordinary flat flows for which $\lambda = 96/\mathrm{Re}$, and lines *2* and *3* approximate the results of the performed research under laminar and turbulent flows, respectively.

In Figure 6 we compare our findings (line 6) with the calculations based on the formulas by R. Manning (3) and M. M. Pavlovskyi (*4*) with theoretical dependency for the open flat flows *1*) (as known, in this case $\lambda = 96/\mathrm{Re}$), and laminar flows in circular ducts (*2*) (in this case $\lambda = 64/\mathrm{Re}$), *5* is the dependency for hydraulically smooth pressure pipelines.

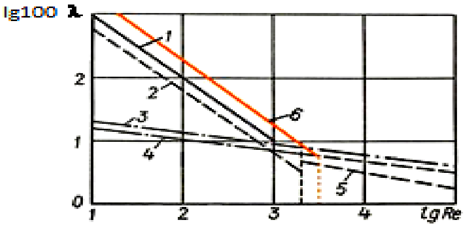


Fig. 6. Comparison of the current calculation methods (1-5) with the obtained experimental data

Since after multiple tests performed on the comparatively smooth concrete surface floated with cement (which can be prepared in the lab settings) we obtained the dependency

$$\lambda = 167/\mathrm{Re},$$

which differed essentially from the classic one for flat flows with the smooth bed surface ($\lambda = 96/\mathrm{Re}$), we decided to perform research based on the actual runways (Fig. 7).

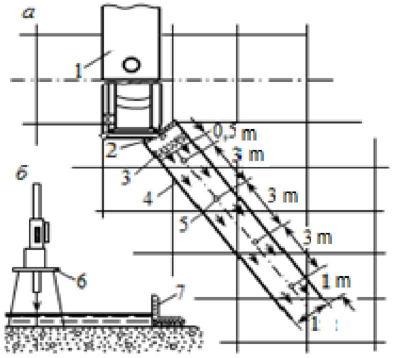


Fig. 7. Scheme to perform research on the *Kyiv Airport's* runway: *1* – vehicle with water supply; *2* – water resistant partition on the surface; *3* – damper (a layer of gravel); *4,7* – tray wall; *5* – points to measure depth values using a point-gauge or an optical ruler OR-1 in the tray; 6 – scheme to install the point-gauge

This research has confirmed the results obtained in the lab settings, but due to a more rough and irregular surface of the runway in Kyiv Airport (at that time), we obtained the results that could be approximated to the equation

$$\lambda = 344/\mathrm{Re}.$$

Resistance coefficient λ proved to be 3.5 times higher than it is used in accordance with the current dependencies for the ordinary laminar flat flows.

3. The objective of this paper is to develop a remote physically feasible method to control water depth values on the surface of the runway.

4. Key findings

The long-term observations performed in the lab settings with an automatic remote sensor within the actual RWY environment suggest it to be rational to qualify the flows observed on the surfaces similar to runways and motor roads as a separate class, the so called low depth flows. To such flows we propose to refer the ones where liquid surface tension is of crucial importance.

Meanwhile we propose to add a term into the Bernoulli's energy-conservation equation –

$$\rho g h + P + \rho V^2/2 + \boldsymbol{\sigma/h} = \mathrm{const}.$$

where ρ is liquid density; g is the gravitational acceleration; h is a water depth value; P is surface pressure; V is flow rate; σ is a surface tension coefficient. A $\rho g h$ complex is the equilibrium pressure; P is the static pressure; $\rho V^2/2$ is the dynamic pressure; $\boldsymbol{\sigma/h}$ is the pressure resistance from the surface tension which is the newly proposed equation term.

The flow work is taken for the specific energy E*, and related to the liquid volume.

In the Figure 8 and the table it is demonstrated how the specific energy E* values change within depths up to 10 mm with a surface slope of 0.01.

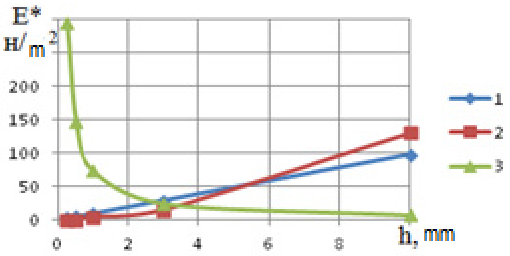


Fig. 8. Flow depth influence on the specific energy E*: *1* – the equilibrium pressure ($\rho g h$); *2* – the dynamic pressure ($\rho V^2/2$); *3* – the pressure resistance from the surface tension (σ/h)

Influence of the surface tension is in inverse proportion to water depth *h,* for this equation term also represents the correspondent work per unit volume w (similar to the rest three equation terms).

In fact, the first equation term reflects the work aimed at mass lifting m in thegravitational field at the height h, e.g. mgh/w = ρgh. The second one reflects the work aimed at the compression of volume w with pressure P Pw/w=P (this factor does not influence the flow under these conditions). The third equation term reflects the work as a result of body motion with mass m at the velocity V- $mV^2/2w = \rho V^2/2$. And lastly, in a similar way the newly introduced term reflects the work of liquid surface tension forces to create surface with an area s - $\sigma s/w = \sigma/h$.

Comparison of three types of specific energy in the low depth flow

h, mm,	ρgh, N/m^2	$\rho V^2/2$, N/m^2	σ/h, N/m^2
0.25	2.45	–	296
0.5	4.9	0.002	148
1	9.8	4	74
3	29.4	14.4	24.7
10	98.1	130	7.4

Figure 9 presents the experiment value of water depth influence on the time of water draining from the axis of the concrete-and-cement runway toward the edge with the slope length equal to 20 m and surface slope equal to 0.01.

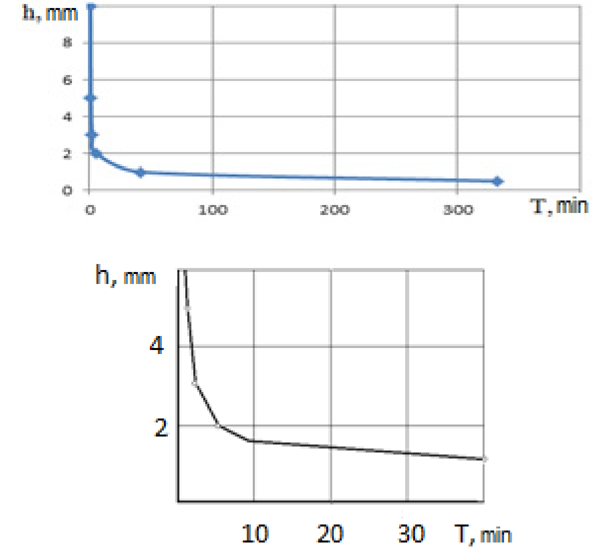
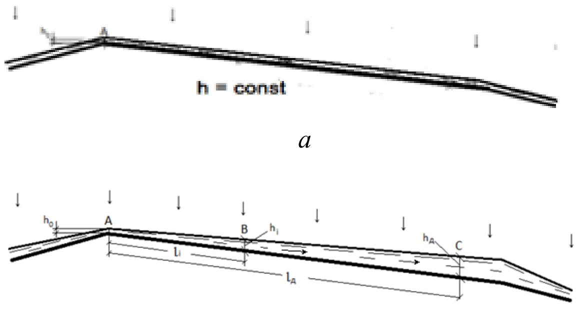


Fig. 9. Depth flow influence on the draining time from the axis toward the runway

As we can see, these data are clearly indicative of a major change of the draining process within depths beyond and above 2-3 mm, which corresponds to a crucial change in relation of surface tension to gravitational and dynamic forces. Water draining is almost non-existent with flow depths beyond 0.5-1 mm. Being under these conditions the surface tension forces exceed gravitational forces by an order, and the water depths stay almost unchanged along the flow length. During precipitation one can observe layer accumulation on the pavement surface (Fig. 10-a). Only with the depths exceeding 1-2.5 mm (under the most common slopes of runways ranging from 0.01 to 0.015) can the surface tension forces level become close to gravitational forces and flow strength when one can observe water movement on the surface. At this time of precipitation the water depth on the surface depends strongly on the distance prior to the slope – Fig. 10-b.



a

b

Fig. 10. Changes in water depths on the runway along the draining line: a- at the beginning of precipitation and with the depths beyond 0.5-1 mm; b - with precipitation and the depths exceeding 0.5-1 mm

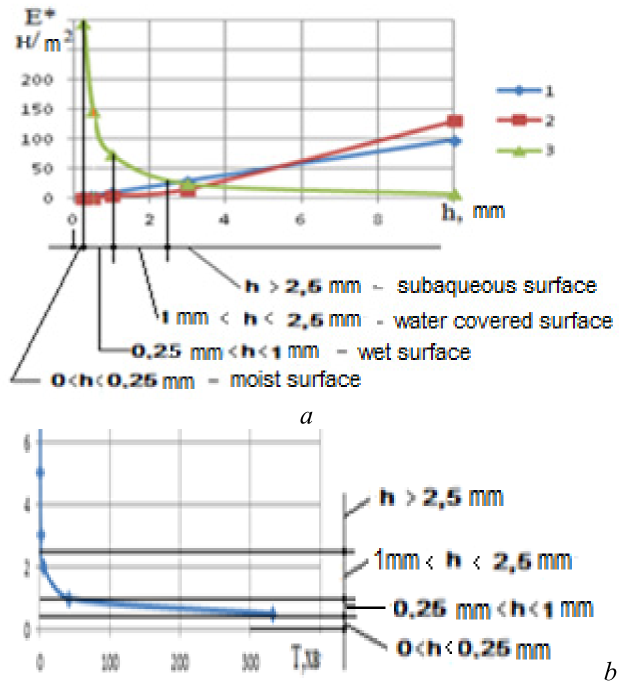
It is interesting to compare the data obtained with the classification of the runway's pavement surface conditions depending on mean water depth h on the pavement surface that was offered until 1986 [11]:

moist surface - h < 0.25 mm;
wet surface - 0.25 < h < 1;
water covered surface - 1 < h < 2,5;
subaqueous surface - h > 2.5 mm.

We do not know the reasons for precisely these values to appear. Some researchers believed the adopted depth values had to do with an inch (2.54 mm).

As it is known, this classification failed to gain popularity by reason of then absence of sensors and methods to assess the conditions of the whole surface of the runway based on their readings.

Fig. 11 shows the boundaries of this classification on the dependence diagram of specific energy types in low depth flow (11-a) and time of water draining on the surface of the runway (11-b).



a

b

Fig. 11. Comparison of the old-school classification of the surface conditions (before 1986): a - with the three type of specific energy in the low depth flow, b - with time of water draining on the surface from the axis towards the runway's edge

This comparison illustrates the physical character of the classification which took into account precisely those water depth values on the surface and their relation to the changes in water surface tension. It becomes clear why particularly with these water depth values exceeding 2-3 mm the conditions of the runway's surface remain practically unchanged. With these depth values the surface tension forces do not influence the flow any more (Fig. 9).

5. Conclusion

The findings pertaining to water draining on the surface of runways during precipitation assisted by the proposed automatic remote water depth sensor discovered the properties which allow to distinguish such flows as a separate class, i.e. *low depth flows.* In respect to such

wet surface - 0.25 □ h □ 1;
water covered surface - 1 □ h □ 2,5;
subaqueous surface - h □ 2.5 mm.

We do not know the reasons for precisely these values to appear. Some researchers believed the adopted depth values had to do with an inch (2.54 mm).

As it is known, this classification failed to gain popularity by reason of then absence of sensors and methods to assess the conditions of the whole surface of the runway based on their readings.

flows we obtained more precise dependencies which allow us, using the sensor readings, to define water depth on the whole surface of the runway, improve the method of water depth control on the runway and increase safety and aerodrome capacity. In the follow-up study we will consider a method to assess the condition of whole runway surface based on the sensor readings and determine the required quantity of sensors and their locations.

References

[1] International Standards and Recommended Practices. Aerodromes. Volume 1. Aerodrome Design and Operations Annex 14 to the Convention on International Civil Aviation Fifth Edition, ICAO, Montreal, 2009 (In Russian).

[2] Airfield Maintenance and Supply Service Manual in Civil Aviation in the USSR (NAS GA-86). Vozdushnyj Transport Publishing House – M.: 1987. - 287 p.

[3] Russian Federation Civil Aerodrome Operation Manual (REGA RF-94) -M.: Vozdushnyj Transport Publishing House, 1996. -193 p. (In Russian).

[4] *Kryvenko Yu. M., Andrushchak L. M.* KIIGA (from the Kyiv Institute of Civil Aviation Engineers) Inventor's Certificate No. 1125473 Liquid Depth Sensor on the Pavement Surface MKI 01 23/14. Published 23.11.84, bulletin No. 43 (In Russian).
Kryvenko Yu. M. 2002. Remote Control of the Runways' Surface Conditions.
[Bulletin of the National Aviation University]– K. 1(12). – P. 188–192. (in Ukrainian)

[5] *Kryvenko Yu. M.* Experimental Studies of Low Depth Flows. Official Journal of the Ukrainian Academy of Engineering. – K. : 2010. – Issue 1. – P. 168–173(In Russian).

[6] *Krjwenko Ju., Beljatynsij A., Klimenko I., Prentkovskis O.* Experiment research into shallow flows of rain-water on the airport runways. Transbaltika 2011. Proceedings of the 7th International Scientific Conference. May 5–6, 2011. Vilnius.

[7] *Krjwenko Ju., Beljatynskij A., Prentkovskis O.*. Experiment research into shallow flows of rain-water on the airport runways. Transbaltika 2011. Proceedings of the 7th International Scientific Conference. May 5-6, Gedeminas Tehnikal Universiti, Vilnius , Lithuania. 2011. – P. 181-185.

[8] Airfield Water Disposal and Drainage System Design Manual – M., MGA, GPIiNII Aeroproekt, 1982, - 60 p.

[9] Construction Norms & Regulations. SNiP 2.05.08-85. Aerodrome. State Construction Committee of the USSR. M: 1985, - 59 p. (In Russian)..

[10] Airfield Maintenance and Supply Service Manual in Civil Aviation in the USSR (NAS GA-80). Publishing House Vozdushnyj Transport – M.: 1981. – 311 p. (In Russian).

Received 24 June 2015.

Ю. М. Кривенко. Дистанційний спосіб контролю глибини шару води на поверхні злітно-посадкових смуг

Національний авіаційний університет, просп. Космонавта Комарова, 1, Київ, Україна, 03680
E-mail: krivenko.yuliy@yandex.ua

Наведено результати дослідження стікання води по поверхні злітно-посадкових смуг, під час проведення яких використовувався автоматичний дистанційний датчик глибини шару води. Отримані результати дозволяють удосконалити спосіб контролю глибини шару води і підвищити безпеку польотів та пропускну здатність аеродрому.

Ключові слова: безпека польотів; датчик глибини шару води; злітно-посадкова смуга; коефіцієнт зчеплення; стікання води.

Ю. Н. Кривенко. Дистанционный способ контроля глубины слоя воды на поверхности взлётно – посадочных полос

Национальный авиационный университет, просп. Космонавта Комарова, 1, Киев, Украина, 03680
E-mail: krivenko.yuliy@yandex.ua

Приведены результаты исследования стекания воды на взлетно-посадочных полосах во время осадков. В исследованиях использовались автоматические дистанционные датчики глубины слоя воды. Полученные результаты позволяют усовершенствовать способ контроля глубины слоя воды, повысить безопасность полетов и пропускную способность аэродромов.

Ключевые слова: безопасность полетов; взлетно-посадочная полоса; датчик глубины слоя воды; коэффициент сцепления; стекание воды.

Krivenko Julij (1939). Candidate of Technical Sciences. Associate Professor
National Aviation University, Kyiv, Ukraine.
Education: Kyiv Institute of Civil Aviation Engineers, Kyiv, Ukraine (1970).
Research area: reliability and safety of electromagnetic valves in aircraft systems.
Publications: 55.
E-mail: krivenko.yuliy@yandex.ua