The Advantageous Statical Metrological Properties of the Pneumatic Sensor with Two Skewed Nozzles

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ABSTRACT. *In the article, the concept and the main statical metrological properties of the pneumatic sensor with two skewed nozzles are presented. The sensor was designed to improve metrological characteristics of the pneumatic sensors by means avoiding the axis-symmetrical outflow. Investigations have proved that generally static characteristic of the sensor is advantageous comparing to the simple pneumatic gauges, i.e. it has higher sensitivity for the same measuring range. Fluctuations of the outflowing air in the measuring slot are smoother, so they don't limit the increase of the measuring range. There are also more possibilities of forming the characteristics of the sensor depending on application requirements.*

Key words: pneumatic sensor, length measurement

1. INTRODUCTION

Pneumatic measuring systems are widely applied in technological processes in order to measure dimensions both after machining and in in-process operations. There are some merits of the pneumatic measurements that determine their wide application, e.g. simple construction, non-contact measurement, high accuracy and high sensitivity of the measurement system, removing any particles from the measured surface with a compressed air stream etc. Some demerits, however, limit the area of their applications. These problems are mostly connected with extending the measuring range (the wider is the range, the smaller is the sensitivity) and defects in the sensitivity graph.

The pneumatic sensor works as a flapper-nozzle valve. The pressure in the chamber depends on the displacement of the flapper surface and for some values of the slot width that dependence is proportional. To enlarge the measuring range the sensitivity must be decreased by means of replacement the inlet nozzles with ones of bigger diameter. Furthermore, in many cases there are fluctuations in the sensitivity graph that decrease the proportional area of the characteristics (fig.1). Many efforts has been undertaken to find out the ways of improvement of the air outlet conditions (e.g. changing nozzles orifices into conical or special profiled shape) that would eliminate such faults. At present possibilities of such changes seem to be over, especially as new constructions of pneumatic sensors like ejectors have been invented. However, they are much more complicated and more expensive in manufacturing though their metrological properties are substantially better than these of simple sensors. Double nozzled pneumatic sensor was thought to be a solution that using a not complicated and cheap construction would enable to reach better results with further improving possibilities.

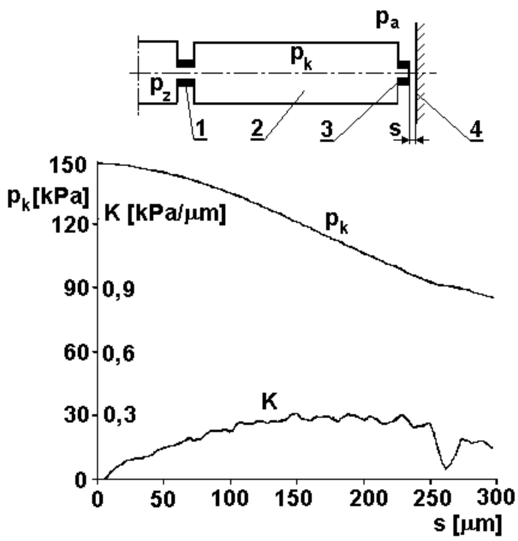

Fig.1. Simple pneumatic sensor (a) and its static characteristic (b). 1 - inlet nozzle, 2 - measuring chamber, 3 - measuring nozzle, 4 - flapper

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2. THE IDEA OF THE PNEUMATIC SENSOR WITH TWO SKEWED MEASURING NOZZLES

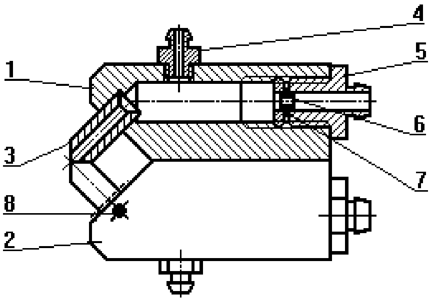

Fig. 2. Skewed nozzles pneumatic sensor

The pneumatic sensor with skewed nozzles was designed to avoid the axis-symmetrical airflow in the measuring slot. The body of the sensor (fig.2) consists of two parts, i.e. 1 and 2. Two measuring nozzles 3 are positioned at the right angle to each other and fastened with a screw 8, so it is possible to replace the measuring nozzles with the ones of different dimensions. The common head of the nozzles surface is placed at the 45° angle to their axis. The pressure in each chamber is measured by separate sensors connected to the joint 4. The feeding hoses are separate, too, and they are connected to the joint 5. The compressed air flows through the replaceable inlet nozzle 6 sealed up with the o-ring 7.

More attention must be paid to the outlet port. It is formed by both measuring nozzles, so its shape depends on the position of the common head surface (see fig. 3). When the surface is placed in 1-1 section, there will be a point orifice. Section 2-2 corresponding to the nozzles axes intersection makes an oval shaped orifice of two nozzle channels connected with one another. Eventually, there are two oval shaped outlets of the divided nozzles in section 3-3. On one hand, the position of the head surface determines the size of the outflow (the closer it is to the section 3-3 the larger is the outflow) because the outflow surface depends on the perimeter of the outlet orifice:

$$S_W = s \times l \tag{1}$$

where: S_W - the outlet surface,

s - the slot width,

l - perimeter of the outlet orifice.

This perimeter as a function of the head surface position is shown in the fig. 4 (h_c=0 in the section 2-2 on the fig.3, h_c>0 between 1-1 and 2-2, h_c<0 between 2-2 and 3-3).

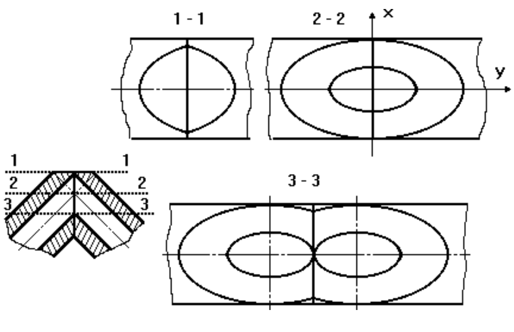

Fig. 3. The outlet port forming possibilities

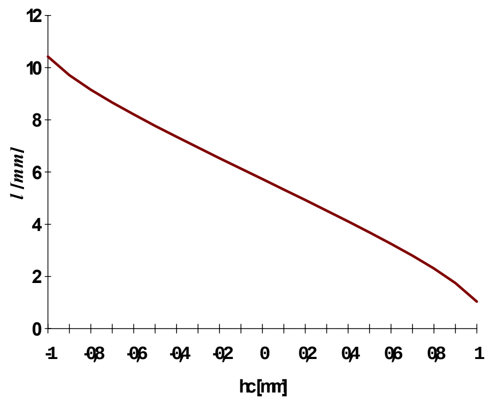

Fig.4. Influence of the head surface position h_c on the perimeter of the outlet orifice.

On the other hand, the influence of one stream to another is different in different head surface positions. For example, when the surface is placed approximately between 1-1 and 2-2 sections, the streams are completely mixed before leaving nozzle, while between 2-2 and 3-3 sections they become mixed partly inside the sensor and partly in the measuring slot outside the sensor. It is clear that two streams cannot be mixed before leaving the sensor in the head position 3-3. Moreover, the flat width depends not only on the d_c/d_p rate (the outer diameter to the inner diameter of the measuring nozzle), but also on the position of the common head surface. The figure 5 shows the changes of the flat width

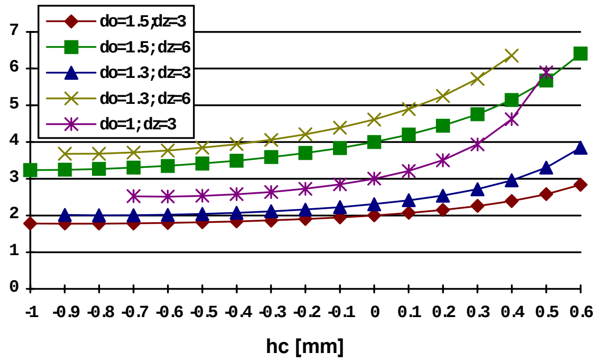

Fig.5 The flat width rate $\sqrt{A_{cz}/A_{ot}}$ depending on the flat surface position h_c.

as a function of the measuring nozzles head position, where h_c is the distance between the head surface and the nozzles axes intersection point.

The flat width is expressed here as a square root of the flat surface A_{cz} to orifice surface A_{ot} ratio. This value corresponds to the d_c/d_p rate for simple sensors [2]. The shapes of these curves are different for different nozzles so that similar flat width is available only for certain h_c. It is very important that influence of the h_c on the flat width is smaller when the outer diameter is closer to the orifice diameter, and that between sections 2-2 and 3-3 (negative h_c) value $\sqrt{A_{cz}/A_{ot}}$ changes very little. For example, sensors with measuring nozzles with d_p=1,5; 1,3; 1,0 mm and with the flat width equal to 4 for h_c=0 would have the flat width 3,302; 3,263 and 3,241 for h_c=-0,70 mm.

These characteristics of the outlet port must be taken into consideration, because all metrological properties of the sensor are different in different configurations. For example, the sensors with the same h_c=-0,750 mm and the same inlet nozzles $d_{w1}=d_{w2}$=0,985 mm, but different flat width, have different static characteristics. Not only the bigger flat forms higher sensitivity like in the simple sensors [1, 2], but also the fluctuation appears again in the sensitivity graph.

3. STATIC METROLOGICAL PROPERTIES

The main metrological characteristics of the sensor are static characteristic (pressure in the chamber p_k as a function of the slot width s) and the sensitivity characteristic ($K=\Delta p_k/\Delta s$). They depend not only on the inlet and outlet nozzles diameters, but also on the common head surface position, because of the different outlet orifice, as it was described above. The graph in the fig.6 shows that for higher value of h_c the measuring range becomes substantially better with a little worse sensitivity. In further investigations it was found out that the best characteristics may be achieved when the head surface is placed between sections 2-2 and 3-3 (see fig.3).

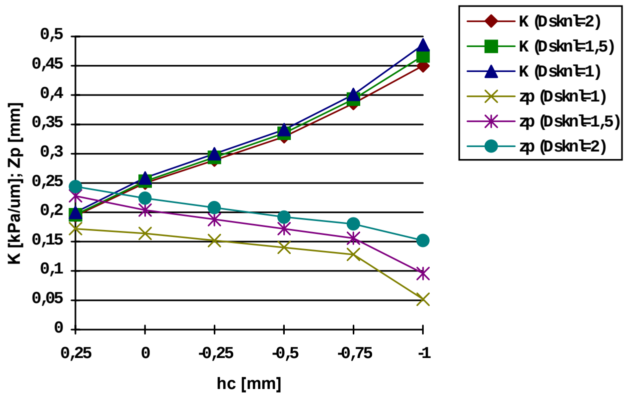

Fig.6. Sensitivity K and measuring range z_p graphs for different values of the linearity error D_{sknl}.

As it was mentioned, measuring chambers are fed separately. It is possible to put different inlet nozzles to reach asymmetrical outflow, as well as to close one inlet and feed another. This way the characteristics of the measuring pressure signals in chambers are of different sensitivity and linearity. In some cases one of those signals is better, in others it is advantageous to use the differential pressure signal. Generally differential mode eliminates outflow instability and in most cases is highly recommended. Fig. 7 is the example of such characteristic.

Each sensitivity characteristic in the graph turns down as the slot grows more than 200 μm, while sensitivity of the difference characteristics ΔK remains about 0,3 up to 300 μm. Fig. 8 presents the static and sensitivity characteristics of the sensor with only one measuring chamber being fed (d_{w1}=1,510 mm). This way one chamber (active) works as a simple pneumatic sensor with skewed measuring nozzle and another one (passive) as an ejector. The stream of expanding air in the measuring slot causes the pressure changes in the passive chamber. As a result, the passive channel has got its own static characteristic, better than that of active channel. It is very important that such a characteristics are available when the flat surface is positioned close to the 3-3 section, but its position depends also on the flat width. For the measuring nozzle with d_p=1,500 mm and outer diameter d_z=3,0 mm good characteristic occurs when h_c=-0,750 mm (see the graph in the fig.8). To obtain similar characteristic for the nozzle with d_p=1,500 mm and outer diameter d_z=6,0 mm the distance h_c must be equal to -0,500 mm.

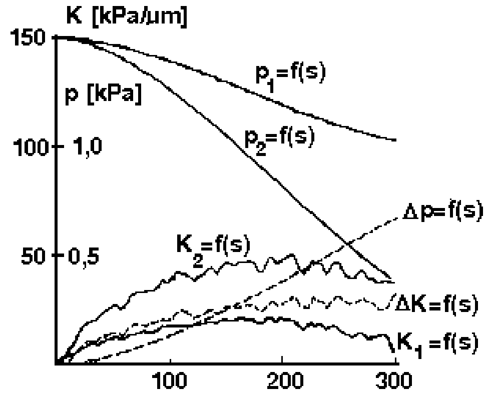

Fig.7. Single chamber static characteristics of pressure p_1=f(s) and p_2=f(s) and of pressure differences Δp=f(s), sensitivity curves for those characteristics K_1=f(s) and K_2=f(s) and for difference ΔK=f(s) of the sensor with h_c=-0,500 mm and with different inlet nozzles (d_{w1}=0,985 and d_{w2}=1,510mm).

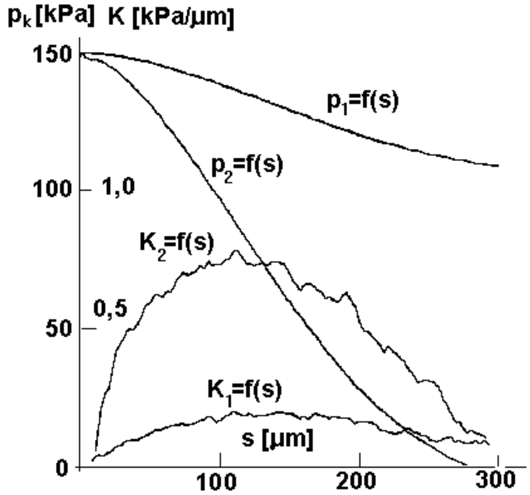

Fig.8. Static characteristics of the double-nozzled pneumatic sensor with only one chamber being fed.

This may be explained when the influence of the flat width on the static characteristics of the sensor is taken into consideration. As it was mentioned above, the bigger flat width is applied, the higher sensitivity has got the sensor. This is true for both simple and double-nozzled sensors, independently on the feeding symmetrical or not. Hence, either flat width or flat position may be changed to obtain similar properties of the sensor.

4. CONCLUSIONS

When it is needed to increase sensitivity or the measuring range of the simple pneumatic sensor, the inlet or the measuring nozzles are replaced. The increase of the measuring range always causes the decrease of the sensitivity and worse linearity. For double-nozzled sensor there are some more possibilities, as:

- change of the inlet or measuring nozzle diameter,
- change of the head surface position,
- change of the measuring nozzles outer diameter (nozzles of the same diameter but different flat width).

Moreover, varying the inlet nozzles diameters it is possible to reach the needed characteristic for one channel or for differential mode. These improving operations are not limited by fluctuations in the sensitivity graph. In effect, comparing to the simple gauges, it have wider measuring range for the same sensitivity.

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