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GENERAL MECHANICS

COMPUTATION OF PNEUMATIC TAPE TENSION SENSORS FOR MAGNETIC STORAGE DEVICES

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1. Introduction

The tape tension provides a contact with the tape drive guide ways and exercises an ascendancy over the quality of the record and the writing processes. The tension variation provokes variation in the average tape speed, tape's pressure over the magnetic head, the cassette's density and exact winding, the tape's inclination and side displacement. The tension's nominal value and tolerance are for different tapes standardized. In the tape drives with vacuum and lever buffers, the tension is determined from the air underpressure or through the spring suspensions parameters. It is out of control during the operation time. In the "reel to reel" drives the tension is determined from the pneumatic sensors placed in the cassette's electric motors feedback control. The tape bearings air pressure in front and behind the magnetic heads is under control, or a specially designed tape bearing is for the same purpose used. The pressure dependence on the air consumption is used. The tape speed above 5 meters per second is achieved when the tape tension varies in the limits of 0.25 N [1].

In that paper a survey of the pneumatic tension sensors designed for high density mass storage devices is prepared.

2. Pneumatic conversion of the measuring signal

The tape tension is monitored by the active control device. Its block scheme is represented on Figure 1. The air pressure is led to the pneumatic sensor which is used as the primary control unit. The received information is converted in an electrical signal and it is sent to a Transitional Converter

(TC). The latter generates command pulses which are transmitted to the Power Amplifier and the cassette electric motors.

The pneumatic sensor is a manometer measuring device [2], Figure 2. The air of stabilized operational pressure P enters the input chamber A. Through the entrance nozzle which section is f_1 it penetrates in the measuring chamber B and from it through the output nozzle with a section f_2 flows out in the externally pressurized tape bearing. The flowing section is of cylindrical shape limited from the f_2 and the magnetic tape. Apparently, the measurement pressure p depends on the operational pressure P, the tape bearing pressure p_1, the sections f_1, and f_2 and the distance h_0. The exact determination of this dependence is extremely difficult. That is why an approximation method that gives the results enough efficient for practical purposes will be described.

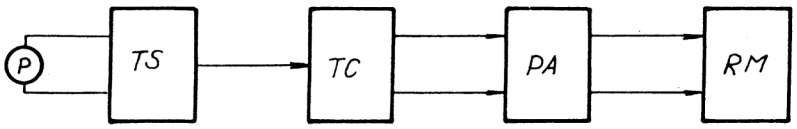


Fig. 1

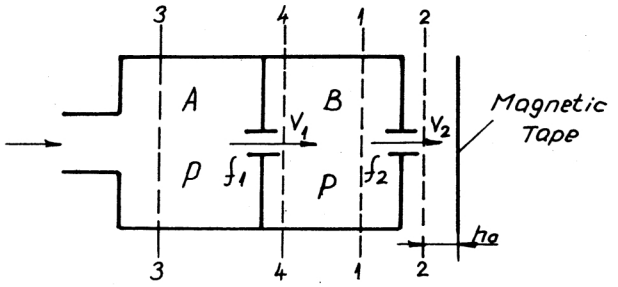


Fig. 2

By little overpressures the air contraction could be neglected and the Bernully's law referred to the flow in the sections $1-1$ and $2-2$ could be used. For the measuring chamber of good volume at which $V_B \approx 0$ the output nozzle flowing speed out is determined by the equation:

$$V_2 = \alpha_2 \sqrt{2g(p - p_1)} \tag{1}$$

where:

α_2 – the consumption ratio through the output nozzle;

p_1 – the tape bearing pressure.

From the Bernully's equation written for sections 3 – 3 and 4 – 4 and $V_A \approx 0$ for an input chamber of good volume, the input nozzle flowing speed is determined as follows:

$$V_1 = \alpha_1 \sqrt{2g(P-p)} \tag{2}$$

where:

α_1 – the consumption ratio through the input nozzle.

After substitution of (1) and (2) in the continuous flow equation is received:

$$p = \frac{P + \left(\frac{\alpha_2 f_2}{\alpha_1 f_1}\right) p_1}{1 + \left(\frac{\alpha_2 f_2}{\alpha_1 f_1}\right)^2} \tag{3}$$

It is assumed that for nozzles with equal geometric forms and comparatively equal sizes $\alpha_1 = \alpha_2$. Because $f_1 = \pi d_1^2/4$ and $f_2 = \pi d_2 h_0$, the equation (3) can be transformed in:

$$p = \frac{P + \left(\frac{4d_2}{d_1^2} h_0\right)^2 p_1}{1 + \left(\frac{4d_2}{d_1^2} h_0\right)^2} \tag{4}$$

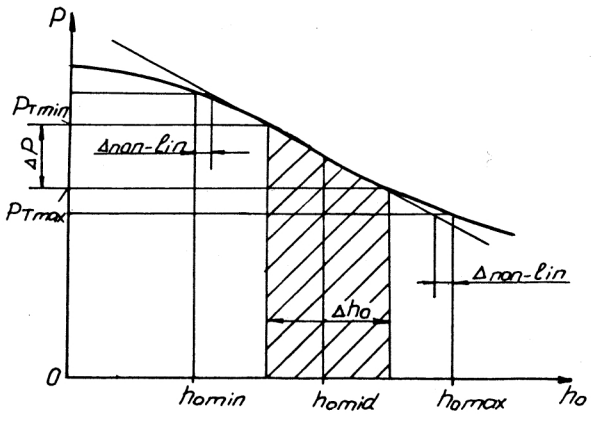


Fig. 3

The graphical expression of (4), shown in fig. 3 represents the characteristics of the pneumatic sensor. The characteristics has comparatively linear form in the part of $h_{0\min} \div h_{0\max}$. Its slope determines the sensitivity or the transmission ratio:

$$K_{h0} = dp/dh_0 \tag{5}$$

If $f_2/f_1 = 4d_2h_0/d_1^2 = x$, from (4) is received:

$$p = \frac{P + x^2 p_1}{1 + x^2} \tag{6}$$

The graphics of (6) has linear part in the range of $x_{\min} \div x_{\max}$. As $x_{\min} \approx 0.4$ and $x_{\max} \approx 0.8$, it can be received that:

$$0.4 = \frac{4d_2}{d_1^2} h_{0\min}; \quad 0.8 = \frac{4d_2}{d_1^2} h_{0\max} \tag{7}$$

From (5) follows:

$$K_{h0} = \frac{dp}{dx} \cdot \frac{dx}{dh_0} = \frac{2x}{(1+x^2)^2}(p_1 - P)\frac{4d_2}{d_1^2} \tag{8}$$

In the linear part of the range can be accepted that $2x/(1+x^2)^2 = 0.63$ [2] and equation (8) can be expressed as:

$$K_{h0} = -0.63(P - p_1)\frac{4d_2}{d_1^2} \tag{9}$$

If (1) is differentiated and the consumption ratios are nearly independent from the variation in the operational and measuring pressures, the relative error is defined as:

$$|\varepsilon| = \frac{dp}{\Delta p} = \frac{dP}{P} \cdot \frac{p}{\Delta p} \tag{10}$$

where:

dp – measuring pressure error, caused by fluctuations in the operational pressure;

Δp – a measuring range expressed in pressure units;

dP – maximal deviation of the operational pressure from the nominal value, set up at certain operational mode of the stabilizer (the stabilizator's error).

The relative error has maximum at $h_{0\min}$.

3. Computation of the pneumatic sensors

The basic sensors parameters are: d_1, d_2, P, Δh_0 and ε. Their theoretically determination is very difficult, because of the assumptions in deducing different formulas. As an example the assumption for incompressible of the air leads to divergences in the theoretical and experimental characteristics. For that reason several experimental data and dependences are used here.

The operational pressure P is equal to the output pressure of the compressor, which serves the tape drive. The diameter of the output nozzle is accepted to be $d_2 \geq 1$ mm. Since the deviation between d_2 and the tape bearing's holes diameter is large, it is accepted that the sensor has not influence on the gap under the magnetic tape.

The gap h_0 under the tape axis is defined for the used tape bearing according to [3]. To guarantee operation in the linear part of the sensor characteristics, the nominal value of h_0 ought to be near to h_{0av}. The diameter of the input nozzle is defined from [7] for $x_{av} = 0.6$:

$$d_1 = \sqrt{\frac{4d_2}{0.6}} h_{0\text{nom}} \tag{11}$$

For the accepted measuring method (nozzle - baffle) the following relation must be observed:

$$h_{0\text{nom}} \leq 0.25 d_2 \tag{12}$$

The operational range Δh_0, fig. 3, is defined from the limited values of the gap, which corresponds to the admissible maximal and minimal tension force. The algorithm given in fig. 4 is used, based on:

$$h_0 = \frac{TR}{2bEtF} \tag{13}$$

where:

T – tape tension force;
R – tape bearing radius;
$2b$ – tape width;
E – modulus of tape elasticity;
t – tape thickness;
F - tension coefficient.

$$\Delta h_0 = h_{0T\max} - h_{0T\min} \tag{14}$$

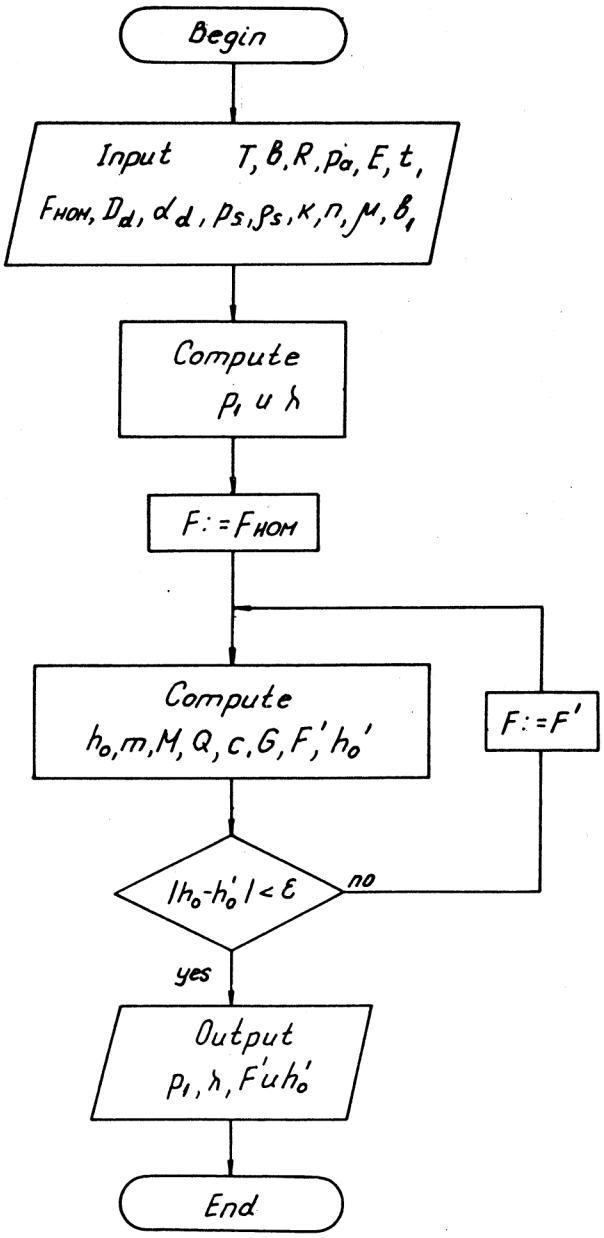


Fig. 4

It is checked if the received value of Δh_0 is in the range defined from (7). The limited values $p_{T\max}$ and $p_{T\min}$ of the measuring pressure and the range of the pressure variation are defined for the limited values of h_0 from (4).

The relative sensor errors $\varepsilon_{\max}$ and $\varepsilon_{\min}$ are defined at time of reading the stabilizer's operational pressure error for $p_{T\min}$ and $p_{T\max}$ from (10). The acceptable operational range is set up after determination of the corresponding measuring pressure errors $dp_{\max}$ and $dp_{\min}$:

$$p_{T\max} + dp_{\min} \leq p \leq p_{T\min} - dp_{\max} \tag{15}$$

The relative non-linearity of the characteristics is defined according to fig. 3 for the nominal measuring pressure:

$$\delta = \frac{\Delta_{\text{nonlin}}}{\Delta h_0} \tag{16}$$

The transmission ratio is a function of p_1 and its absolute value decreases with raising of h_0.

The pressure transducer is selected according to the determined values of p. The use of piezoresistive elements is recommended because of the availability of small tension transducers from the membrane type with high own frequency. Their output is linear, without pulsations and it depends proportional on the pressure. A differential transducer in which one pressure is selected to be atmospheric is selected.

In time of defining the sensors parameters one must know that the device adjustment is required every time when the device is used. That is due to the unprecised computation method and the unavoidable nozzle sizes deviations from their nominal values. In that case the desired characteristics can be drawn by variation in the operational pressure P.

4. An example

The application of the proposed method of the pneumatic sensor computation will be illustrated at the selection of the pressure to voltage semiconductor transducer used in 12.7 mm cartridge tape drive. The sensor is mounted in the externally pressurized tape bearing which radius is 15.8 mm and directs the magnetic tape movement to the receiving reel. The compressor's output operational pressure is 31 kPa.

The nominal gap between the tape and the bearing is $h_{0\text{nom}}$ = 0.006275 mm [3]. From (11) is received that d_1 = 0.2045 mm in case that d_2 = 1 mm. It is accepted that d_1 = 0.2 mm. The condition (12) is observed. According to (7) the sensor characteristics is linear in the range of 0.004 to 0.008 mm when p_1 = const.

The operational range Δh_0 is defined according to (4) for tension force T = 2.2 N + 15% ($T_{\max}$ = 2.53 N, $T_{\min}$ = 1.87 N). The following results are drawn by using the algorithm shown in fig. 4.

	p_1	λ	F	h_0
$T_{\max}$	0.113983	0.124927	1.992235	0.007135
$T_{\min}$	0.110681	0.092337	1.902898	0.005521

$\Delta h_0 = 0.001614$ mm and it lies in the linear part of the characteristics. The values of the measuring pressure are as follow:

$p_{T\min} = 25.943800$ kPa;

$p_{T\text{nom}} = 25.351689$ kPa;

$p_{T\max} = 24.812407$ kPa;

$\Delta p = 1.131393$ kPa.

In case that $dP = 0.31$ kPa (the stabilizer's error is 1%) the following values are received: $\varepsilon_{\max} = 0.229308$ and $\varepsilon_{\min} = 0.219308$, respectively $dp_{\max} = 0.259428$ and $dp_{\min} = 0.248124$.

The tape tension force control device must be set up in such manner that the measuring pressure is to be in the limits of 25.060531 kPa to 25.684372 kPa. The relative nonlinearity, i.e. the $p_{T\text{nom}}$ deviation according to the line, crossing the points $(h_{0T\min}, p_{T\min})$ and $(h_{0T\max}, p_{T\max})$ is 0.0562 (5.62%).

According to the above computations and the design considerations, a miniature piezoresistive pressure transducer of fast pressure to voltage transformation is selected, produced by MICRO SWITCH, model 136PC05 [5]. The transducer has the following parameters: overpressure range of 0 to 0.345 bars (from 0 to 34.5 kPa), full scale output 50 ± 1.5 mV, sensitivity 0.145 ± 0.004 mV/mbar (1.45 ± 0.04 mV/kPa) and minimum starting time 1 msec.

5. Conclusion

The considered pneumatic sensors have simple design and small sizes. They are with high reliability because the air stream is used for nozzles self-clearing. They are embedded in the existing tape drive components and use the available overpressure source. The applying of the considered theoretical formulation is acceptable because the high smooth of the tape and the ventilated side guides of the bearings have not significant influence for the air flowing via the small gap. As the consequence of the joint operation with the tape bearings the characteristics linearity decreases and the range of the measuring pressure decreases too. That requires the usage of high sensitive transducers. The relative error can be minimized through the stabilizer's error diminution.

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