PARAMETRICAL AND STRUCTURAL OPTIMIZATION ON THE RESPONSE TIME OF THE ANALOG PNEUMATIC DIAPHRAGM TRANSDUCERS OF THE LINEAR DISPLACEMENTS WITH VARIABLE ENTRANCE VALVES

Vladímir. B. Bókov
"STANKIN" Moscow State Technological University
The Army Polytechnic School (ESPE)

RESUMEN[*]

Los transductores diferenciales analógicos neumatrónicos (mecatrónicos) de diafragma son los elementos más importantes de los medidores y sistemas de control neumatrónicos. Estos transductores se ubican en los medidores entre un sensor neumático y un segundo mecanismo de transmisión o transductor electrónico. En sistemas neumatrónicos de control estos se usan primero como un nexo entre los amplificadores de poder. Frecuentemente este transductor es una transmisión mecánica única que vincula los sistemas con los sensores jet.

Ellos tienen un tiempo bajo de respuesta y producen la reducción dinámica de todo el sistema.

Analizar los fenómenos con modelos lineales de regresión es una de las maneras más eficientes para construir dispositivos analógicos neumatrónicos con propiedades deseables. Por lo que es posible mejorar los dispositivos neumatrónicos y desarrollar una tecnología avanzada de diseño de este tipo de indicadores. Este trabajo se dirige a dispositivos de diafragmas para mecanismos de acción con movimiento progresivo único. En estos dispositivos, el hundimiento de diafragma elástico ocasiona traslaciones de sus partes de trabajo.

Los resultados de las investigaciones experimentales de los transductores neumatrónicos rápidos de diafragma permitieron la optimización parametrical y estructural de estos transductores en el tiempo de operación. El método de gradiente se usó combinando con la experimentación de factores fracciónales (el método de Box - Wilson). Los esquemas nuevos de los transductores se obtienen con una alta dinámica y de características estáticas mejoradas.

ABSTRACT

The results of the experimental investigations pneumatic quick-acting diaphragm gauges have been presented as the results of the parametrical and structural optimization of these gauges on the time of operation. The gradient method was used combining the fractional factor experiment. The new schemes of the gauges are obtained with high dynamics and improved static characteristics.

1.- Introduction

The analog pneumatic diaphragm differential transducers are the most important elements of the pneumatic measuring and control systems. These transducers are located between a pneumatic (jet) sensor and a second transmission mechanism (driving gear) or transducer in measuring devices. In pneumatic control systems they are used as a first link of a power amplifiers. Often this transducer is a single mechanical transmission link in systems with jet sensors. They have low response time, producing the reduction of the dynamics of all the system.

Analyzing regressions lineal models is one of the most efficient ways to build pneumatic analog devices with desirable properties. Therefore, it makes possible to improve pneumatic devices and develop an advanced design technology of this kind of gauges.

This article is directed to diaphragms devices for action mechanisms (driving gear) for progressive movement only. In these devices, the sag of elastic diaphragm causes displacement of their working parts. Nowadays, they are being widely used due to the lack of mechanical friction in packings and its higher sensitivity to pressure.

2.- Initial pneumatic micrometry gauge description

These pneumatic gauges are constructed according to the principle of blast intensity compensation. The blast intensity through the outlet variable valve of the working chamber is compensated by the blast intensity through the entrance variable valve. In this case, the pressure in the working chamber can be constant or equal to the pressure in the back pressure chamber. This device works by the principle of force's compensation.

The initial pneumatic micrometry gauge is shown schematically in Figure 1.

It comprises two pipelines 1 and 2 intended to be supplied in parallel from the same compressed gas source 3, respectively through one calibrated inlet

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[*] Correspondencia a: Dr. Vladímir B. Bókov, ECUADOR, Sangolquí, Av. El Progreso S/N, Centro de Investigaciones Científicas, ESPE.

orifice 4 and one regulating orifice 5. One of the two pipelines, (pipeline 1 that is the regulating pipeline in the example shown) has a primary outlet regulating orifice 6 to the atmosphere.

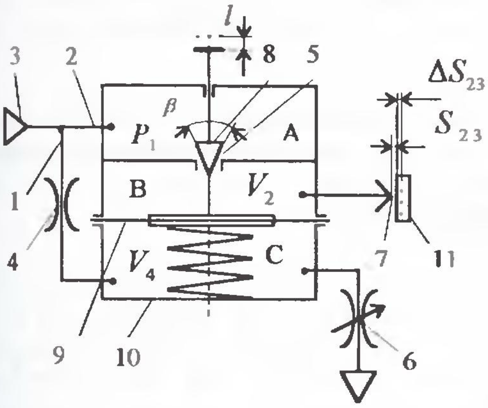

Figure 1. Principal scheme of the initial pneumatic gauge

The other pipeline or measuring pipeline 2, is fitted with an outlet orifice to the atmosphere by a measuring jet 7 (nozzle-flapper sensor), while the regulating pipeline 1 is fitted with another outlet orifice 6 to the atmosphere. Here the outlet orifice 6 of the regulating pipeline 1 is of constant cross-section, and only one measuring orifice, i.e. 7 of pipeline 2, is used with the device. The measuring pipeline 2 has an entrance orifice 5 in which is mounted a tapered portion 8 axially movable in the said orifice to modify the effective section of the latter, and forming a part of a rod integral with a very flexible diaphragm 9, which is capable of being deformed, without strain, in a chamber 10. The diaphragm 9 sealingly divides the interior of the chamber 10 into two compartments B and C linked respectively to the two pipelines 1 and 2.

The air free pass through the measuring jet 7 and a tapered portion 8 is situated in a top situation when the flapper 11 is removed. This leads to maximum expense of air through the device. It increases a pressure in a chamber B and causes it to move down the diaphragm 9 and a tapered portion 8 when the flapper 11 is appeared in front of a measuring jet 7. The movement will be continued as far as a new balance is settled between different pressures on the diaphragm 9, weight of movable part and effort of the pressing spring (spring effort). The moving rod is located in aerostatics guide for the removal of the influence of dry friction.

In any case, the measurement is read on the indicating instrument joined to the tapered portion 8 that is moved by the diaphragm 9 under the influence of the differential pressure to which it is subjected before attaining its position of equilibrium for which the pressure is the same for both pipelines. Because here is used a very flexible diaphragm and the pressure in a chamber B is almost constant, a mass of the air in chamber B is changed very little, the response time is also slow.

3.- Extreme experiment with initial pneumatic micrometry gauge

One factor experimental investigations on gauges with volume compartment B equals to 45 cm^3 and weight of the moving parts equal to 15 g, has shown that the response time is formed 60 - 70 mc. These results are obtained by means of taping one factor experiments during the changes only three parameters: corner of the cone of the valve, the section of the penetration of the measuring jet or the stiff of the spring. For the definition an influence of all kinds of essential designing and technological parameters are conducted more fully for this gauge, to define the value of the best dynamic properties.

The first creation step for the pneumatic apparatus is the theoretical investigations then its design is chosen, the optimum parameters and conditions of working. There are many parameters that influence on dynamic properties and therefore the best method of investigation is the Design of Experiments.

During a preparation, the gauge projected along with its parameters of design and conditions of working may by independently alter according to the matrix of the plan of experiment. Construction of the transducer is shown in Figure 2.

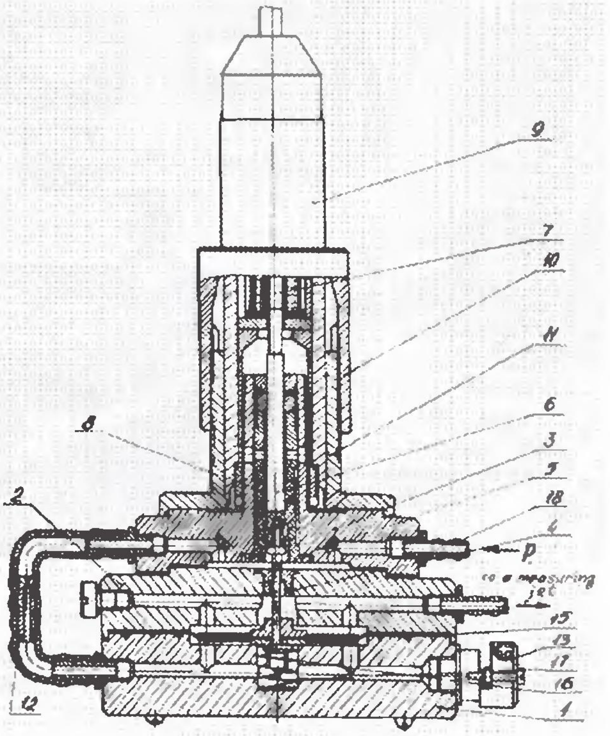

Figure 2. Pneumatronic transducer: 1 - base, 2 - interlayer, 3 - cover, 4 - inserted seat, 5 - stem, 6 -

armature stock, 7 - axial armature, 8 - air bearing, 9 - inductive transducer case, 10 - nut, 11 - conical grip, 12 - constant throttle, 13 - adjustable throttl, 14 - hard centre, 15 - diaphragm, 16 - stock nut, 17 - spiral spring, 18 - pipe connection.

The response time was received as response function and the entrance factors were included: P_1 - entrance pressure; V_2 - volume of the working chamber; V_4 - volume of back pressure chamber; f_{14} - the area of the passage section of the entrance orifice of the back pressure chamber; F_{24} - effective area of the diaphragm; K - driving spring of elastic system and f_{23} - the area of the passage section of the measuring orifice. The other's entrance factors of the active experiment are supported constantly.

The values of parameters of the entrance variable orifice of the chamber B was received as follows: diameter of orifice d_{12} = 3 mm, diameter of the rod d_{12r} = 2,5 mm, corner of the cone of the valve $\beta = 35^o$. These dimensions of the valve guaranty the ordinary making, small expenditure of the compressed air and the working range of displacements of the moving rod equal to +/- 0,3 mm. The mass of the moving details in all tests had maintained equal to 19,8g.

The rubber diaphragm is used with thickness equal to 0,35 mm. The measurement equipment was the measuring orifice with a diameter of 2 mm in combination with the oven-door.

It used inductive mod. 234 sensor (mass of the moving details equals to 15,4 g) of the measuring mod. 217 electronic system of the firm "Caliber", Russia, as a second electric transformer, but the differential-transformation sensors of the firm "Schaevitz Engineering" may be used and similar ones also. The transient characteristics of this gauge are obtained on special stand is shown in Figure 3 and equipped by fast-response recorder.

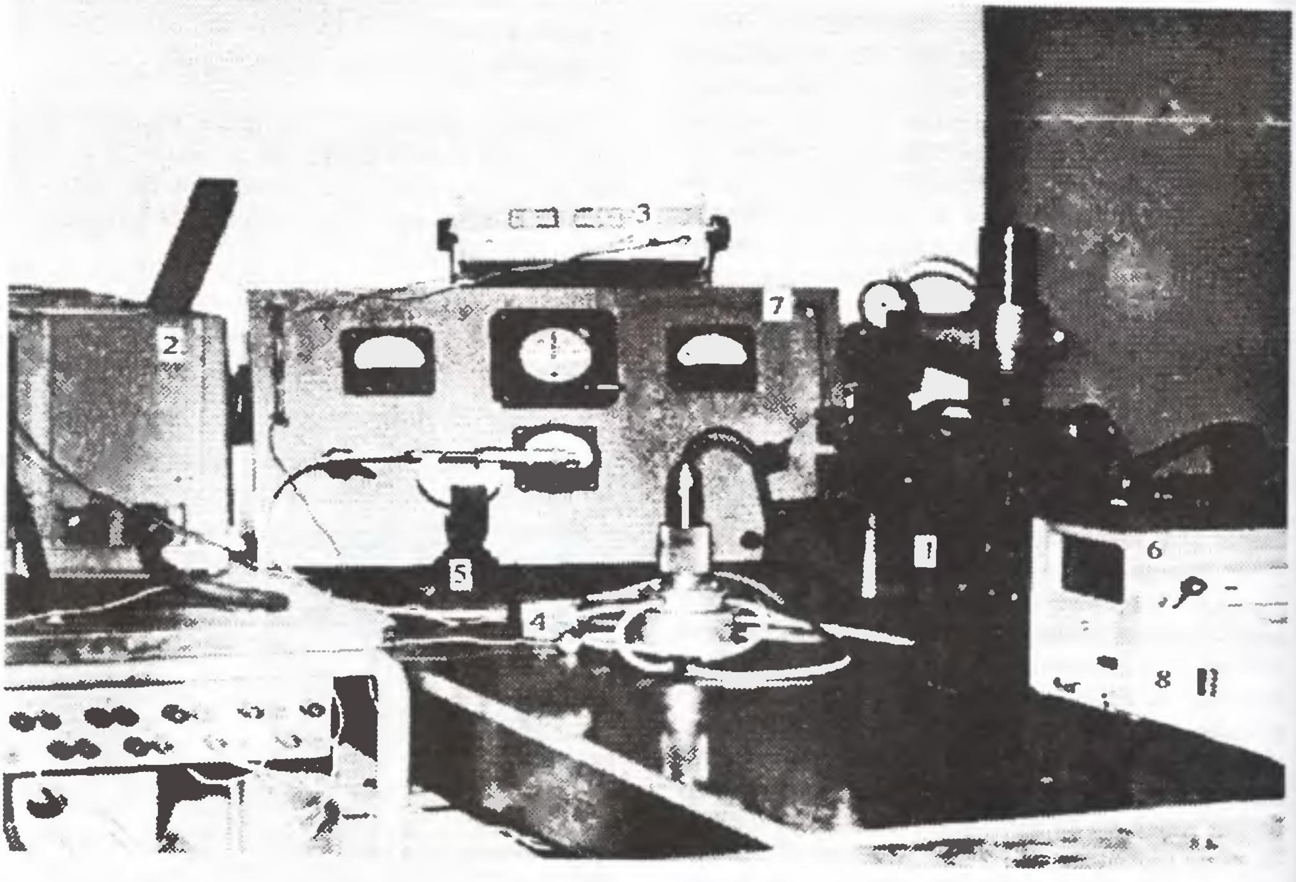

Figure 3. Experimental equipment: 1 - stand mechanic section, 2 - loop oscillograph, 3 - direct current power source, 4 - electropneumatic transducer with adjustable outlet throttle, 5 - adjustable counterpressure throttle, 6 - measuring mod. 217 electronic system, 7 - stand electric section, 8 - fast-response recorder.

In compliance with preliminary investigation results (Reference 1) the values of levels and variation intervals of the factors have been selected (lines 1 - 5 of Table 1), and in chosen with varying intervals that are pursuing an object, to produce a model of operation process of the gauge near of linear function.

Extreme experiment with initial pneumatic micrometry gauge. Table 1.

No	Investigation factores	F_{24}, mm^2	f_{23}, mm^2	f_{14}, mm^2	V_2, cm^3	k, N/m	V_4, cm^3	P_1, kPa	Tests resultes t, c
2	Main level	1232	2,327	0,747	26,44	161	8,09	49,0	
3	Varying interval	61	0,154	0,147	3,14	52	1,36	9,8	
4	Upper l evel	1293	2,481	0,905	29,58	211	9,35	58,8	
5	Lower level	1171	2,173	0,610	23,30	107	6,83	39,2	
6	Factor´s codes	X_1	X_2	X_3	X_4	X_5	X_6	X_7	
7	General replica								
8	Test - 1	-	-	-	+	+	+	-	0,143
9	Test - 2	+	-	-	-	-	+	+	0,088
10	Test - 3	-	+	-	-	+	-	+	0,148
11	Test - 4	+	+	-	+	-	-	-	0,137
12	Test - 5	-	-	+	+	-	-	+	0,098
13	Test - 6	+	-	+	-	+	-	-	0,088
14	Test - 7	-	+	+	-	-	+	-	0,140
15	Test - 8	+	+	+	+	+	+	+	0,109
16	Additional replica								
17	Test - 9	+	+	+	-	-	-	+	0,095
18	Test - 10	-	+	+	+	+	-	-	0,151
19	Test - 11	+	-	+	+	-	+	-	0,088
20	Test - 12	-	-	+	-	+	+	+	0,099
21	Test - 13	+	+	-	-	+	+	-	0,122
22	Test - 14	-	+	-	+	-	+	+	0,150
23	Test - 15	+	-	-	+	+	-	+	0,101
24	Test - 16	-	-	-	-	-	-	-	0,132
25	Steep rising								
26	Regression coeficientes	-0,0146	0,0134	-0,0095	0,0040	0,0021	-0,0006	-0,0072	
27	Varying intervals	-0,8855	0,0021	-0,0014	0,0126	0,109	-0,0008	-0,0706	
28	Step	-0,89	0,002	-0,0014	0,013	0,11	-0,001	-0,07	
29	Mentales tests	....	....	....	....	....	....	....	....
30	Test No 113	1333	2,101	0,905	24,97	149	8,20	56,9	0,071
31	Mentales tests	....	....	....	....	....	....	....	....
32	Test No 209	1418	1,909	1,039	23,72	138	8,30	63,6	0,058
33	Mentales tests	....	....	....	....	....	....	....	....
34	Test No 302	1501	1,723	1,169	22,52	128	8,32	70,1	0,051
35	Mentales tests	....	....	....	....	....	....	....	....
36	Test No 415	1602	1,497	1,327	21,04	115	8,51	78,0	0,049
37	Mentales tests	....	....	....	....	....	....	....	....
38	Test No 614	1779	1,099	1,606	18,44	94	8,70	92,0	**0,043**

For the minimization the number of tastes, the matrix of planing wear used the replica 2^{7-4} /Reference 2/. It has the ability of small solution and the effects of lineal are mixing with interactions of couple. With a goal to remove an influence on the coefficients of regression the coupled effects, had realized an additional replica in which matrix all signs had changed on opposites (method of pass).

Matrix of planing and the results of the tests had been done with randomization that are brought together in Table 1 (lines 6 - 23). On the results of the tests and using the known equations /Reference 2/, had calculated the coefficients of regression that also are presented in Table 1 (line 25).

Significance of the coefficients of regression had appreciated by Student criterion.

The equation of regression obtained in view:

$$t = 0{,}1181 * X_0 - 0{,}0146 * X_1 + 0{,}0134 * X_2 - 0{,}0095 * X_3 + 0{,}0040 * X_4 + 0{,}0021 * X_5 - 0{,}0072 * X_7,$$

where t - an operation time of the gauge.

Adequacy of the equation of regression had verified by Fisher criterion.

It is limited to the linear approach of the model that has been obtained. It is realized the steep ascent (lines 24 - 37). The operation time of this gauge had decreased in 1,5 times as seen from the Table 1.

The static characteristic of the obtained gauge is the sensitivity (the amplification factor) which equal to 1,43. The linear section of the dependency of a displacement of the rod from the variation of the measuring circular clearance S_{23} (in the presence of non-linear equal to 3%) is composed 0,3 mm on the measuring circular clearance.

4.- Analysis of the experiment results and synthesis of a new devices

It has analyzed, the tendencies of the variation the values of the set of constructive factories F_{24}, f_{14}, V_2, K and V_4. The extreme experiment in the linear model has been placed at the speed of response of the gauge, may be increased by means of perfecting its construction. So, the necessity to decrease the value of the factor K for this gauge, is connected with the direction of force action of elastic compressed spring directed to meet of the mobile detail's transference in the moment of the gauge operation and coincides with direction of the inertial force. As a result, this is increasing the inertia of the gauge. Therefore, for increasing the speed of response of the gauge it is necessary to put the spiral spring in the chamber B /Reference 3/, as it shown on Figure 4.

In this case the placing of the compression spring creates the direction of action of the elastic force coincidence with direction of the mobile detail's motion. It allows to decrease the influence of the inertial force and to shorten the response time. In the presence of this, the value of the factor V_2 will decrease and the value of the factor V_4 will increase, on the value of the volume of the spring. This according to the regression equation will also assist in increasing the speed of response of the gauge.

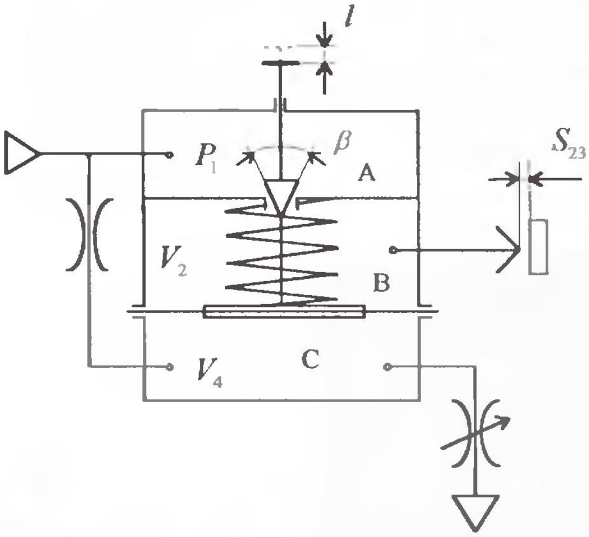

Figure 4. Principal scheme of the gauge with a spring in the working chamber

The results of testing the gauge with spiral spring in the working chamber and the gauge with spiral spring in the chamber of back pressure had shown that the first gauge has the speed of response in 1,5 times decreased then the second gauge. These tests were conducted with spiral spring with values of hardness 110 N/m and 210 N/m that is situated by turns in the working chamber and in the chamber of the back pressure.

The other factor that is very interesting for the perfecting of the scheme of the investigated gauge is the constructive factor f_{14}. The increase of this factor according to the regression equation is directed to the increase of the blast intensity through the gauge. For the elimination of this defect it's possible on the entrance of the back pressure chamber to install a throttle valve with the clear opening alternated in the process of working. In the presence of the initial state, the clear opening of this throttle valve, should have provided a minimum blast intensity, but in the moment of operation the clear opening of this throttle valve, increased and provided the increase of the pressure in the back pressure chamber. At this time, the acceleration is reached of the transient process elapsing in the back pressure chamber which decrease the pick-up time of the gauge.

The gauges arrive at a maximum increasing the quick-acting, if it has been installed, the compression spiral spring in the working chamber, and is replaced by the entrance constant valve of the back pressure chamber, on the changeable the construction in the entrance valve of the working chamber Figure 5.

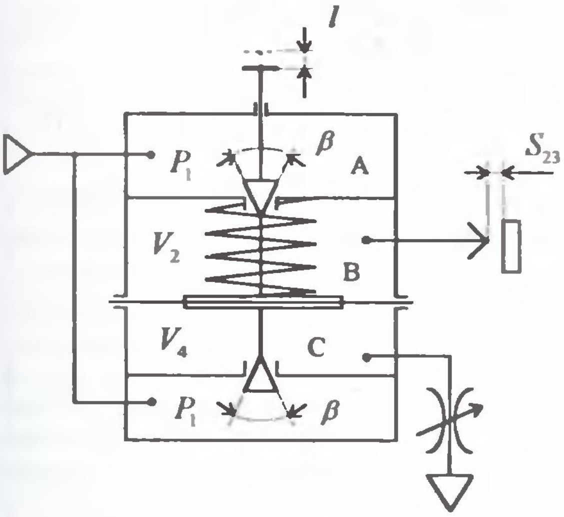

Figure 5. Principal scheme of the pneumatic gauge with high quick-acting

Here it has been kept the possibility on the scheme with the back pressure as on the differential scheme.

5.- Extreme experiment with new gauge

For the optimum results the definition of the gauge parameters on the scheme Figure 4, with the maximum quick-acting, is used for the procedure of extreme experiment, the same as the gauge on the scheme of Figure1.

In the total capacity of the all input factors to the active experiment it has been included: V_2 - volume of the working chamber; F_{24} - effective area of the diaphragm; β - corner of the cone of the entrance valves; f_{23} - the area of the passage section of the measuring orifice; K - driving spring of elastic system; P_1 - entrance absolute pressure; V_4 - volume of the back pressure chamber.

In the organizing of the extremal experiment, the same fractional saturated plan in the assembly with "method of pass" was used.

The values of main levels of factors, varying intervals of the factors and the values of the upper and lower levels are brought together in Table 2.

The testes of the experiment according to the matrix of planing had been done with randomization and the results of the testes have been repeated twice.

For the results of the tests of the active experiment the known equations /Reference 2/, were used in calculating the coefficients of regression and the equation of regression resulting as:

$$t = 0{,}0610 * X_0 + 0{,}0035 * X_1 + 0{,}0070 * X_2 - 0{,}0020 * X_3 - 0{,}0030 * X_7,$$

where t - an operation time of the gauge.

Also, the steep rising realized uses the equation of regression of the process operation. In the result, the time of operation of this gauge, has been decreased approximately five times more than the initial optimal gauge, on scheme of Figure 1 and has been obtained 10mc.

6.- The feather structural decreasing the time operation and improvement of the static characteristics of the new gauges

With the improvement of dynamic characteristics of the gauges, with variable entrance valves, it is easy to reach the improve static characteristics /Reference 4/. In case of needing to increase the sensibility (amplification factor) it is necessary, for example, in the variable entrance valve of the back pressure chamber, the needle of the cone of the valve has to be placed in the inside as it shown on the Figure 6.

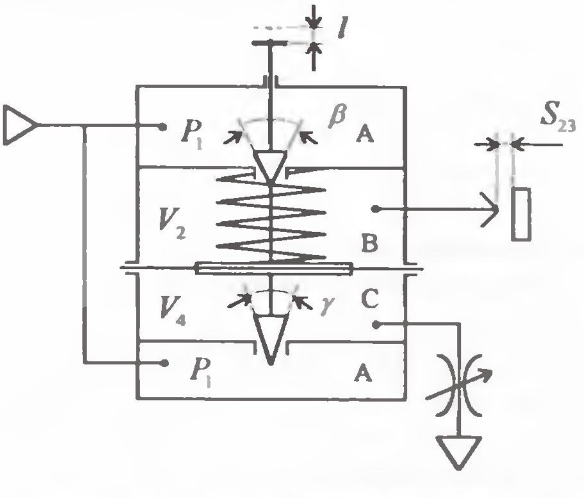

Figure 6. Principal scheme of the pneumatic gauge with increased sensibility

Extreme experiment with new gauge. **Table 2.**

No	Investigation factors	V_2, cm^3	F_{24}, mm^2	α, grados	f_{23}, mm^2	k, N/m	P_1, kPa	V_4, cm^3	Tests resultes t, c
2	Main level	23,43	3340	32,5	1,492	161	55,0	27,06	
3	Varying intervals	1,89	133	2,5	0,079	52	5,0	2,51	
4	Upper level	25,32	3473	35	1,571	211	60,0	29,57	
5	Lower level	21,54	3207	30	1,413	107	50,0	24,55	
6	Factors codes	X_1	X_2	X_3	X_4	X_5	X_6	X_7	
7	General replica								
8	Test - 1	+	+	+	+	+	+	+	0,076
9	Test - 2	+	-	-	-	-	+	+	0,060
10	Test - 3	-	-	+	+	-	-	+	0,044
11	Test - 4	-	+	-	-	+	-	+	0,060
12	Test - 5	-	-	-	+	+	+	-	0,060
13	Test - 6	-	+	+	-	-	+	-	0,066
14	Test - 7	+	+	-	+	-	-	-	0,074
15	Test - 8	+	-	+	-	+	-	-	0,054
16	Additional replica								
17	Prueba - 9	-	-	-	-	-	-	-	0,058
18	Prueba - 10	-	+	+	+	+	-	-	0,070
19	Prueba - 11	+	+	-	-	+	+	-	0,076
20	Prueba - 12	+	-	+	+	-	+	-	0,058
21	Prueba - 13	+	+	+	-	-	-	+	0,064
22	Prueba - 14	+	-	-	+	+	-	+	0,058
23	Prueba - 15	-	-	+	-	+	+	+	0,044
24	Prueba - 16	-	+	-	+	-	+	+	0,064
25	Steep rising								
26	Regresion coeficientes	0,0035	0,0070	-0,0020	0,0013	0,0008	0,0013	-0,0030	
27	Varying intervals	0,0066	0,9310	-0,0050	0,0001	0,0416	0,0065	-0,0075	
28	Step	0,007	0,93	-0,005	0,0001	0,04	0,007	-0,008	
29	Mentales tests	....	....	....	....	....	....	....	....
30	Test No 143	22,43	3207	33,2	1,478	155	54,0	28,20	0,058
31	Mentales tests	....	....	....	....	....	....	....	....
32	Test No 300	21,33	3061	34,0	1,462	149	52,9	29,46	0,044
33	Mentales tests	....	....	....	....	....	....	....	....
34	Test No 500	19,93	2875	35,0	1,442	141	51,5	31,06	0,028
35	Mentales tests	....	....	....	....	....	....	....	....
36	Test No 700	18,53	2689	36,0	1,422	133	50,1	32,66	0,020
37	Mentales tests	....	....	....	....	....	....	....	....
38	Test No 1100	15,73	23,17	38,0	1,382	117	47,3	35,86	0,014
39	Mentales tests	....	....	....	....	....	....	....	....
40	Test No 1500	12,93	1945	40,0	1,342	101	44,5	39,06	**0,010**

Here the angle of the needle cone of the entrance variable valve of the working chamber must be greater than the angle of the entrance variable valve of the back pressure chamber. This is necessary for the gauge to work through the entrance working chamber valve, which has covered itself on a larger value than the entrance back pressure chamber valve and has been approximated in the pressures in the working chamber and in chamber of back pressure equally in the presence of any of the measuring clearance.

For the increase of the measuring clearance diapason it is necessary to examine the type of the gauges in the measuring jet to connect moveless (hardly) in the tapered portion as shown on the Figure 7.

In this case, for example, in the presence of reducing the measuring clearance S_{23}, it is increasing the pressure in the working chamber. It causes the displacement of the center of the diaphragm and the moving stem daunts together with the measuring jet. In this case the measuring clearances are supported constantly with same error of regulation. This displacement of the measuring jet is providing the widening of the range measurements.

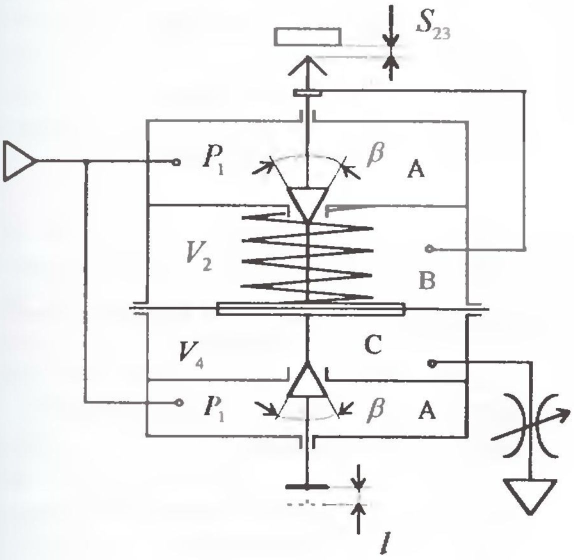

Figure 7. Principal scheme of the pneumatic gauge with widening diapason of measuring

In case of necessity to widen the diapason of measuring, high sensibility and fine dynamic characteristics of the gauge on the scheme Figure 6 it is necessary to measure jet that connects immovable with the tapered portion as it shown on Figure 8.

All methods of structural improvements of dynamic's and static's characteristics of the gauges have been limited to the necessity to work as differential scheme of switching on the scheme with the back pressure.

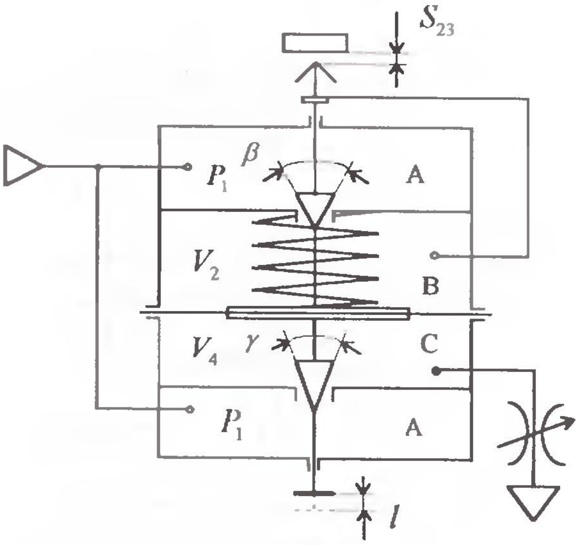

Figure 8. Principal scheme of the pneumatic gauge with increased sensibility and widening diapason of measuring

If it works on the scheme with the back pressure it is possible the further structural optimization on the quick-acting. It is reached as shown on Figure 9 by substitution of the constant tuning output valve on the variable outlet valve of the back pressure chamber.

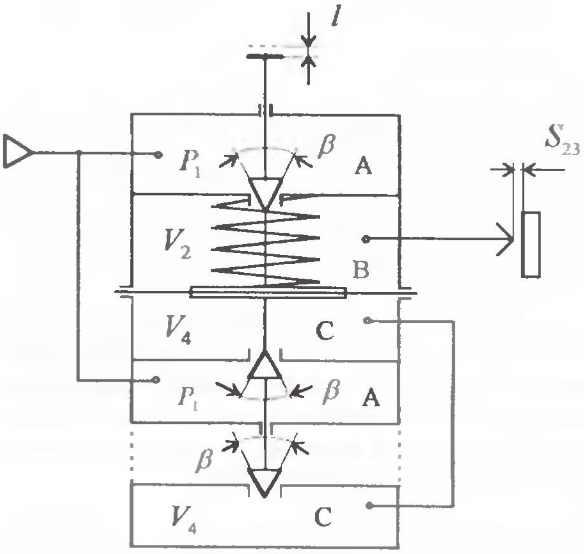

Figure 9. Principal scheme of the structural optimal on quick-acting pneumatic gauge

Moreover all structural methods of improvement of gauges static characteristics have been shown above and may be used here.

For example, the increasing of the sensibility and extending of the range of measuring with a high quick-acting is achieving in the gauge on the scheme Figure 10.

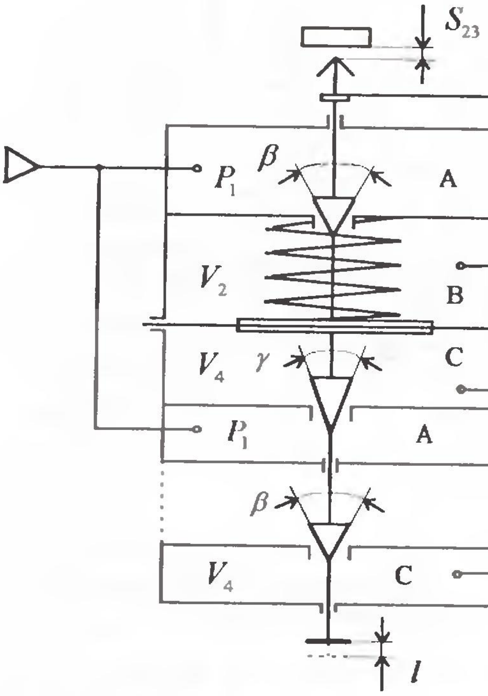

Figure 10. Principal scheme of the pneumatic gauge with structural improved of static's and dynamic's properties

7.- Conclusions

The founded adequate linear regression models of the process of operation of the known gauge has been allowed to optimize its parameters as to define the ways of perfecting the scheme aiming to achieve the maximum quick-acting.

The best effect rising of the quick-acting of the pneumatic analog gauges with diaphragm for the linear measurements is reaching with synchronous optimization of the parameters and improvement of the scheme that are based on the linear regression model of the process of operation these gauges.

Optimization of the constructions of the based gauges in the creation of principally new variable entrance valves pneumatic gauges of the rising quick-acting and with improved static properties.

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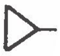
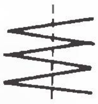
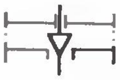
Nomenclature

S_{23}	- Measuring clearance
l	- Displacement of the rod
P_1	- Entrance pressure
V_2	- Working chamber volume
V_4	- Back pressure chamber volume
β	- Top coning angle
γ	- Lower coning angle

Symbol	Description
	Air flow Supply
	Air flow Exhaust
	Nozzle-flapper sensor
	Diaphragm assembly air flow restrictor
	Spiral elastic compression spring
	Alternate (controllable) air flow restrictor
	Air flow restrictor
	Regulated air flow restrictor
	Regulated alternate air flow restrictor