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PRESSURE PULSE GENERATING SYSTEM FOR DYNAMIC CALIBRATION OF SILICON LOW RANGE PRESSURE SENSORS

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Abstract – The dynamic calibration of silicon pressure sensor and whole pneumatic part of the pressure transducers becomes an important problem in many applications. The known methods are not satisfactory for low range sensors. In this paper a simple system for short pulse pressure generation is described. A method for determination of frequency response based on pressure pulse signal is presented. The obtained results show that this method is simply for realisation and useful for low range silicon pressure sensors.

Keywords: silicon pressure sensors, dynamic calibration, pulse pressure source

1. INTRODUCTION

In the case of variable pressure measurements the dynamic characteristic of pressure sensor ought to be known. The application notes not always contain satisfactory information. When the pneumatic measuring chains are considered the dynamic characteristic always should be determined individually.

Different methods of pressure sensors dynamic calibration have been worked out [1], but all of them are rather complicated, expensive and not convenient for common use especially when low range, small dimension silicon pressure sensors are tested. Therefore new methods still are developed [2,3,4,5]. The generating of pneumatic test signal becomes essential in any of them. Two types of that signal are in use: sine wave signal (frequency point-to-point methods) and step or pulse signal (time response methods). For small range pressure sensors the frequency method seams to be very easy in realisation [2,3], but the testing procedure is more laborious. A proposition of time response method is presented in this paper.

2. PRINCIPLE OF THE MEHTOD

The basic structure of measuring chain for dynamic calibration of pressure sensors by means of time response method is shown in Fig. 1a. In this case one essential disadvantage has to be pointed out - the reference transducer of test signal is necessary. In order to avoid that inconvenience, the spectrum of test signal should be flat. The flat spectrum may be achieved if the pressure pulse is very short. A structure of measuring chain becomes much simpler in this case (see Fig. 1b). Therefore, the generating of short pressure pulse is essential for the proposed method.

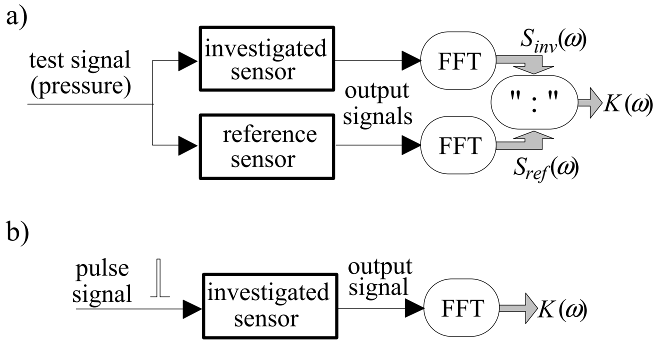

Fig. 1. Measurement chain of time response method for time signal of any shape (a) and pulse signal (b).

3. REALISED SYSTEM

The realised calibration system is shown in Fig. 2. As a source of pressure test signal two kinds of loudspeaker were used: woofer GDN 10/30/2, 30 W, 8 Ω, f_o = 70 Hz and tweeter GWT 9/80/5F, 80 W, 8 Ω, f_o = 1,6 kHz [6].

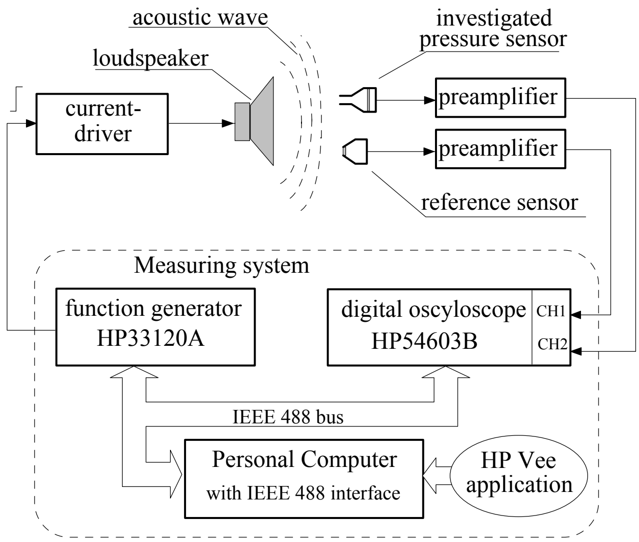

Fig. 2. The realised system for dynamic calibration of pressure sensors by means the time response method.

The loudspeaker is driven by controlled current source. When the current I_L changes rapidly, the membrane moves and in consequence an acoustic wave is generated. Due the loudspeaker and sensors are located in open area the change of pressure has a pulse character even the current changes in the step way.

The two applied types of current driver are shown in Fig 3. The first one (Fig. 3a) is a current amplifier. In this case the current I_L have the step form and available range of current is (-1...1) A. In the second circuit (Fig. 3b) the current I_L is generated by discharging of capacitance and its time function has a pulse character. Amplitude of this pulse depends on the supply voltage U_C and the capacitance C and reach 7 A for U_C equal 100 V. Higher values are not possible because of the loudspeaker limitation. Duration of the pulse depends on the capacitance and parameters of loudspeaker (R, L).

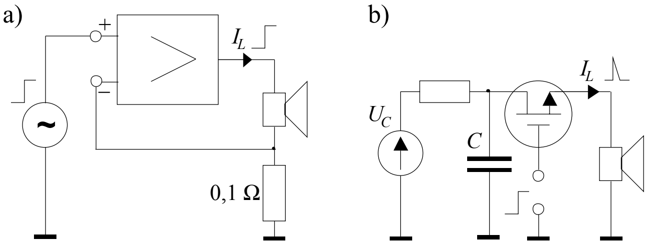

Fig. 3. Structures of current-driver: current amplifier (a) and capacitance discharging circuit (b).

Amplification of the preamplifiers was tune to obtain sensitivity equal to 1 V/kPa in static conditions for the reference and investigated transducers. This allows expressing values of all output signals in pressure units. The anti-aliasing low-pass filters were connected with amplifiers.

The whole system is based on IEEE488 interface and controlled by the HP VEE application. All necessary conversions (e.g. FFT) and calculations (e.g. averaging of spectrum) are included in to this application.

3. RESULTS OF INVESTIGATION

In order to verify the pressure pulse shape the above-described system was tested with Kulite reference sensor type XT-190M with the range of 35 kPa and natural frequency 160 kHz.

Plots of typical current and pressure waveforms in the short time period are shown in Fig. 4. It is visible that in both cases the raising time is very short (less than 70 µs). For the capacitance discharging circuit amplitude of pressure pulse exceeds 0,3 kPa (144 dB relative to 20 µPa) and is three times bigger than for the current amplifier. Pressure pulse of such shape seems to be useful for dynamic calibration of low range silicon pressure sensors but the question is if the spectrum of these signals is flat and width enough. A periodic component of frequency ca. 1,7 kHz is visible in both cases, but amplitude of this component is much higher for the capacitance discharging current driver.

Fig. 5a shows a plot of typical recorded pressure signal when the woofer driven by current amplifier is used as the acoustic pulse source. The time interval is here ten times longer than in case shown in Fig. 4. An additional low frequency component is easy to observe. Frequency spectrum of this signal (see Fig. 6a) enables to estimate the frequency of that component as an equal to 120 Hz. It corresponds to the not completely damped natural oscillation of membrane.

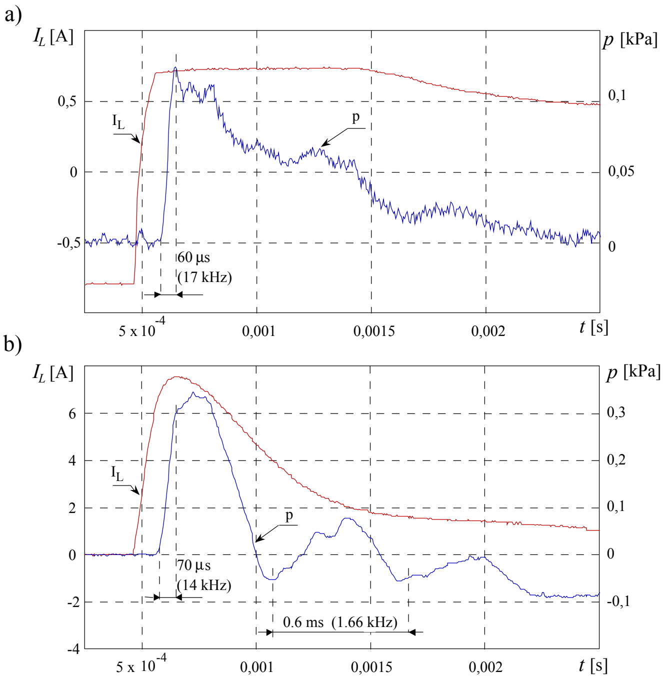

Fig. 4. Plots of current and pressure waveforms for the current amplifier (a) and capacitance discharging circuit (b) as current-drivers.

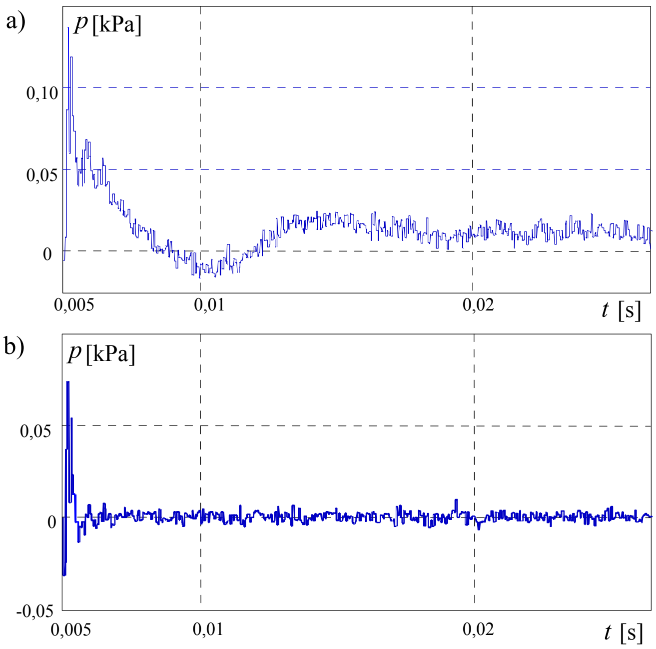

Fig. 5. Output signal of the reference transducer (a) and the recovered pulse component of this signal (b).

By numerical filtering the low frequencies have been cut off from the spectrum. Then the inverse Fourier transform was applied. Fig. 5b shows a plot of a time signal reconstructed after rejection components less than 480 Hz.
It shows that there exists an evident pulse component in the pressure signal generated by the loudspeaker. Spectrum of this component is more or less flat and width enough for examination of investigated sensor frequency response in range from ca. 500 Hz. up to 10 kHz.

The further investigation shows that it is not possible to apply a tweeter as a source of pulse pressure. In this case the spectrum is not flat, the natural frequency of the membrane is ca. 2,1 kHz and is to high (see Fig. 6b).

In Fig. 7 the output signal spectrum of one of the investigated transducers (PS-005-33-D Vigotor, range 5 kPa) is shown as an example. The two resonance frequencies are clearly visible. These frequencies correspond to the analytical model of such transducers. The results obtained by investigations of different silicon pressure transducers in detail are discussed in [7].

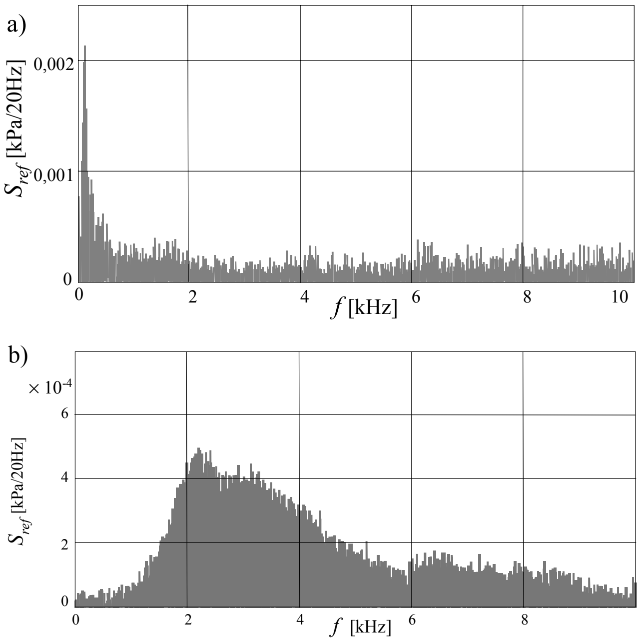

Fig. 6. Spectrum of output signal of the reference sensor when the woofer (a) and tweeter (b) as an acoustic source are applied.

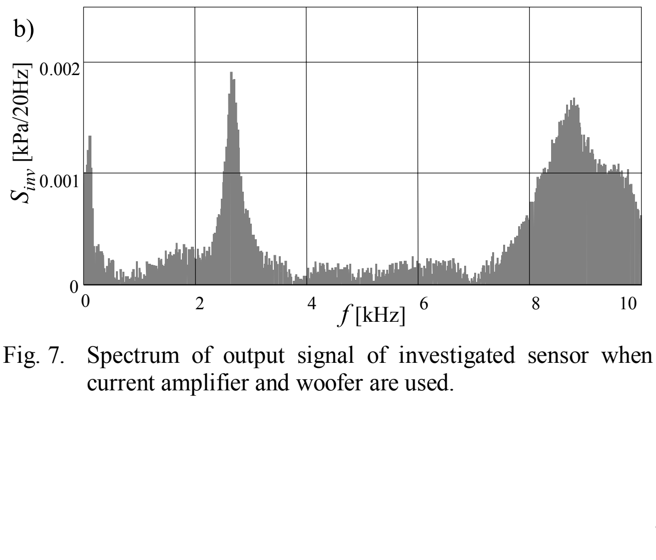

Fig. 7. Spectrum of output signal of investigated sensor when current amplifier and woofer are used.

The analogous spectrum of the pressure pulse obtained by use the discharging circuit as a current-driver is shown in Fig. 8a. As is visible the spectrum is not flat. The most of energy is concentrated in frequency range up to ca. 2 kHz and the maximum is for 1.7 kHz (except the frequency of membrane natural oscillations - 120 Hz). It corresponds to the frequency of electrical oscillation in discharging circuit.

As it was stated in point 2 the poor flatness of spectrum is not good feature when the reference transducer is not used. However, that signal may be useful for determination of investigated sensor resonance frequencies. In Fig. 8b the spectrum of output signal of the above mentioned sensor type PS-005-33-D is shown. The visible maximum can be interpreted as resonance frequencies of this sensor (the same as in Fig. 7). However, in case one of them would be located close to the 1.7 kHz, its determination may be difficult.

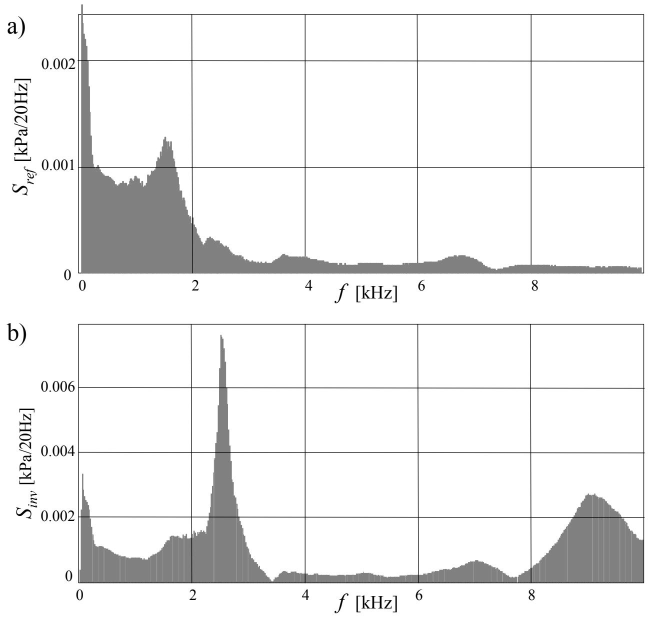

Fig. 8. Spectrum of output signal of the reference sensor (a) and the investigated sensor (b) when the capacitance discharging circuit is used.

When the reference transducer is applied we can determined the dynamic properties of investigated transducer much more precise. Not only values of resonance frequencies may be readout, but also the whole frequency response $K(f)$ may be calculated. This characteristic shows the sensitivity versus frequency and may be calculated as follows:

$$K(f) = \frac{S_{inv}(f)}{S_{ref}(f)}, \quad (1)$$

where $S_{inv}(f)$ and $S_{ref}(f)$ are amplitude spectrum of investigated and reference transducers output signal.

In Fig. 9 the frequency response obtained by this method (curve 1) is compared with the same characteristic determined point by point for sine wave signal (curve 2) [3,5].

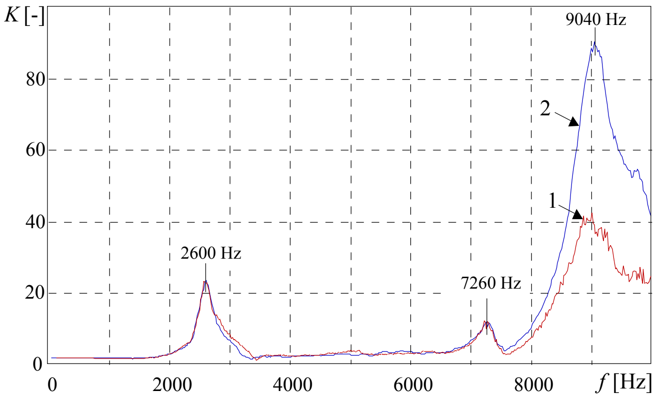

Fig. 9. Frequency response characteristic of investigated transducer obtained by pulse response method (1) and point-to-point method (2).

The compatibility is very good for frequency up to 8 kHz. The higher frequency components of reference signal are comparatively small in reference signal (see Fig. 8b) and this caused that this part of frequency response is not so precise.

The output signals of the reference and investigated transducers are on very low level and therefore noised. In order to reduce the noise influence the frequency response shown in Fig. 9 was obtained by averaging for 500 realisation of the pressure pulse. This is easy to perform in automatic calibration system shown in Fig. 2.

4. PRACTICAL APPLICATION OF THE SYSTEM

The above-described system has been applying for verification of dynamic model of several types silicon pressure sensors. Some more important conclusions are given bellow. Complete results will be published later.

The second order oscillating model is commonly accepted as the dynamic model of pressure sensor of typical construction. Two cases are considered: the Helmholtz resonator model and the "organ pipe" model [7]. The natural frequency is the most important parameter in both of them. This frequency depends on the ratio of the inlet pipe volume to the chamber volume (see. Fig. 11).

The natural frequencies for different situations were calculated and simultaneously experimentally determined. An example of the results is shown in Fig. 10.

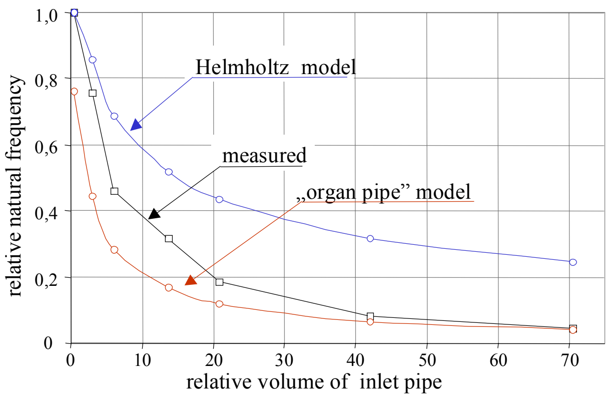

Fig. 10. Plot of the natural frequency versus volume of inlet pipe.

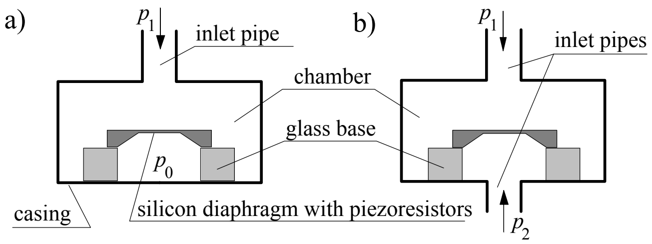

Fig. 11. Structures of silicon sensors for absolute (a) and differential or gauge (b) pressure measurements.

5. CONCLUSIONS

The carried out examination shows that the described pulse response method is useful for dynamic calibration of the low range silicon pressure sensors. The frequency range (0,5 to 10 kHz) is relatively width [1,2,4]. This method is simple for realisation and not very laborious. The required equipment is not very specialised.

In case of the current amplifier as loudspeaker driver is used, spectrum of pulse pressure signal is flat enough to determine the resonance frequencies of sensor under test directly from the spectrum of its output signal. The reference transducer is then not necessary. Unfortunately amplitude of pressure pulse is rather low. It can be three times bigger in case the capacitance discharging circuit is applied. So when the higher amplitude is necessary the second one current driver circuit may be applied. Due to the spectrum of pressure pulse is not flat in this case, the reference transducer ought to be used. That allows determine not only the resonance frequencies, but the characteristic of sensitivity versus frequency, too. The low frequency range in this case reaches 40 Hz and is limited by the loudspeaker.

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