Development of an innovative instrument for the online characterization of high-frequency percussive ventilators

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Abstract—**Sophisticated and expensive equipments are required for measuring the respiratory parameters (pressure and flow) during high-frequency percussive ventilation. The use of pressure transducers of new generation with high sensitivity and reduced response time, proposed in this work, permit to simplify the flow measure and to develop a DSP-based system for acquisition and elaboration of respiratory parameters. The realized system is compact, portable, inexpensive and it presents a wide bandwith permitting the online characterization of high-frequency percussive ventilators. In this paper a description of the designed device is carried out together with a validation procedure in order to compare the measures made by our device with those obtained by a laboratory measurement system of respiratory parameters usually used to calibrate the pulmonary ventilators.**

Keywords— **HFPV, Percussionaire, Instrument characterization, Fleisch.**

I. INTRODUCTION

High Frequency Percussive Ventilation may be defined as flow-regulated time-cycled ventilation that creates controlled pressure and delivers a series of high frequency subtidal volumes in combination with low frequency breathing cycles [1]. In recent years, the usefulness of HFPV has been clinically reassessed as an alternative to conventional mechanical ventilation.

Existing methods for measuring respiratory parameters (pressure and flow) during the high-frequency percussive ventilation employ two different transducers [2] [3]. The first is an unipolar pressure transducer that measures the absolute value of pressure in the upper respiratory tract of the patient, with a magnitude of some tens of H_2O centimetres. This measure is not critical and it is executed using suitable conditioned transducer (Honeywell 142PC05D). The other transducer quantifies the flow by using a Fleisch pneumotacograph, which converts the flow in a differential pressure, subsequently measured by using a high sensibility pressure transducer. The typical values of flow, expressed as litres per second, are converted by the pneumotacograph in a differential pressure measured in millimetres of H_2O.

To increase the sensitivity of the system and to overcome the fast variation of the respiratory parameters in the high-frequency percussive ventilation, it is necessary to condition the output of the transducer with a sophisticated and expensive apparatus (Validyne MP-45 with carrier demodulator) [4]. This fact produces some limitations in the study of percussive ventilator carried out through offline analysis of the acquired values after analogue to digital conversion.

In this paper an innovative acquisition and elaboration DSP system based on the use of pressure transducers of new generation with high sensitivity and reduced response time (ALL SENSORS, Amplified Very Low Pressure Sensors Series) is described.

Such a system results compact, portable and inexpensive and it allows the user to carry out a more correct online characterization of high-frequency percussive ventilators.

II. THE INSTRUMENT

A. Hardware description

The choice of pressure transducer was based on the features comparison of some 12-bit amplified differential low pressure sensors (Table 1).

Table 1 Pressure transducers comparison

Manufacturer	Model	Pressure Range	Response Time
Sensym	ASDX001D44D	±70 cm H2O	2.73 – 1.11 ms
Sensirion	SDP1000-L025	±0.25 cm H2O	40 ms
Sensor Technics	HCLA02X5DB	±2.5 cm H2O	0.5 ms
All Sensors	0.25INCH-D-4V	±0.63 cm H2O	0.5 ms

The block diagram (Fig.1) illustrates the structure of the new acquisition device.

The amplified line of low pressure sensors (ALL SENSORS 0.25INCH–D-4V, 20INCH-G-4V) is based upon a proprietary technology able to reduce all output offset or common mode errors. This model provides a ratiometric 4 volt output with superior output offset characteristics. Output offset errors, due to temperature changes, as well as position sensitivity and stability to warm-up and to long time period, are all significantly improved when compared to conventional compensation methods. The sensor utilizes a silicon, micromachined, stress concentration enhanced

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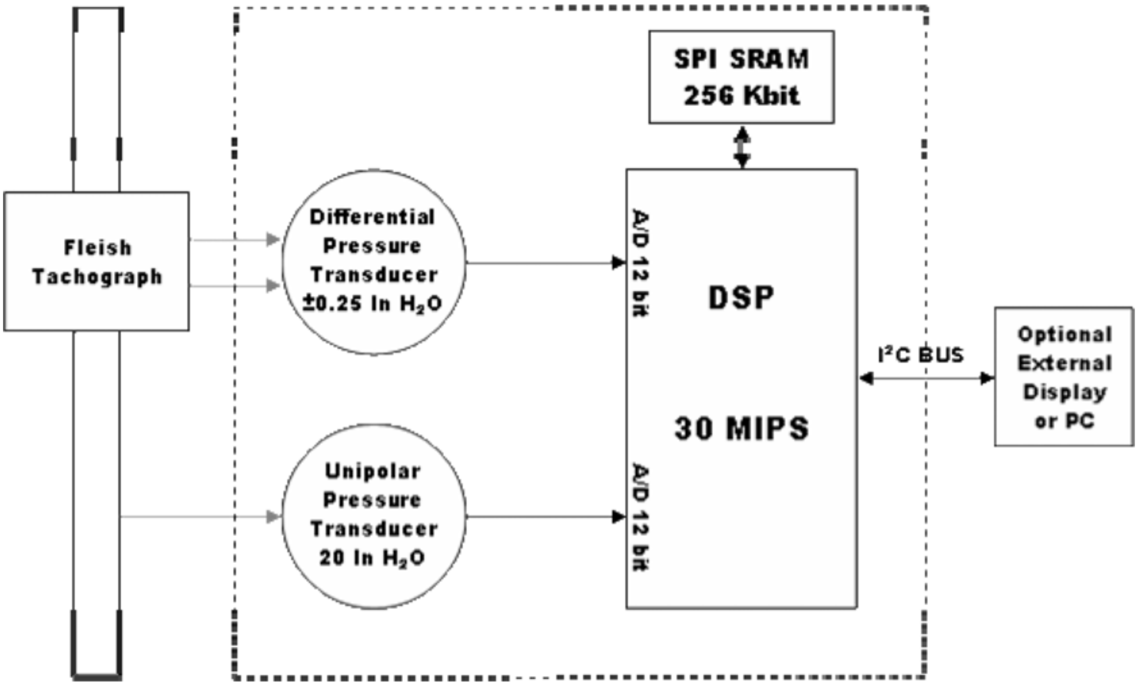

Fig.1 Block diagram of the DSP-based acquisition device.

structure which provides a very linear output to measured pressure.

The DSP (Microchip dsPIC30F2011) is based on a modified Harvard architecture; it operates up to 30 MIPS operation with analogue features (12 bit 200 Ksps A/D converter).

The SPI SRAM (Microchip 23K256) is a recent serial SRAM device used for storage of acquired data. The device is well suited for applications involving bulk data transfers, DSP and other math algorithms (e.g. FFT and DFT).

The acquired samples can be simply buffered and sent to an external device for visualization, memorization and elaboration, using an I^2C bus (offline mode).

Moreover the data can be elaborated directly on the board and the results transmitted in real time to a visualization device (online mode).

Fig.2 shows the device prototype realized in the Biomedical Instrumentation Laboratory at the Trieste University.

B. Software description

In order to verify the reliability of the new device a procedure was established for measuring the volume. This procedure employed a 3-litre calibrating syringe (Fukuda Sangyo, Japan) and a manually simulated respiratory cycle of approximately 12 acts per minute for 120 seconds.

The volume was calculated by integrating the flow; this operation, described in [5] could introduced a maximum error of 3% that can be considered satisfactory and within the accuracy of the employed instruments.

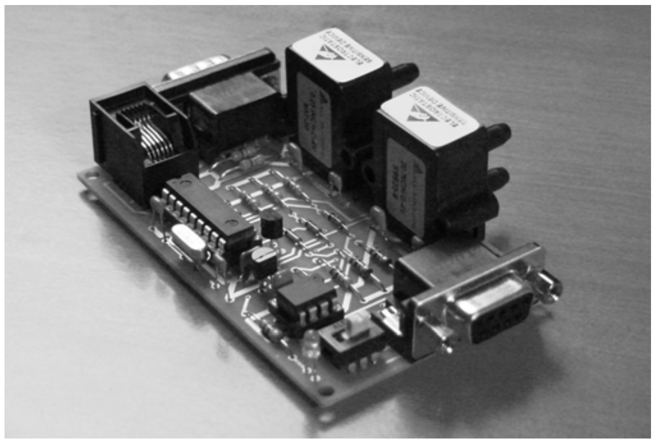

Fig.2 The prototype of the realized device.

C. Test system

In order to study the characteristics of percussive ventilators, after the verification of the device reliability, a test system was produced. The flow output of a Percussionaire

(VDR-4, Percussionaire Corporation, USA) was connected to a lung-simulator (SMS, Medishield, UK), presenting variable R/C parameters, through a laboratory measurement system of respiratory parameters (BIO-TEK, Gas Flow Analyzer VT+ HF) and a Fleisch pneumotacograph (Type 2, 3 L/sec) to which the new device was connected.

The pressure and flow measures were carried out for 240 seconds, setting up on the VDR-4 a respiratory frequency of 15 acts per minute with I/E 1:1 and a percussive frequency of 800 cycles per minute with job pressure of 25 cm H_2O and free expiratory flow. On the lung-simulator a mechanical resistance of 0 cm H_2O/(L/sec) and a compliance of 20 ml/cm H_2O was fixed.

The acquired data was digitally filtered with a low-pass third order Butterworth IIR filter with a cut-off frequency of 400 Hz.

The laboratory measurement system of respiratory parameters supplies directly the measured volume. The volume measured by the new instrument was calculated integrating the flow curves.

III. Results and discussion

The acquired values of flow (Fig. 3), pressure (Fig. 4) and computed volume (Fig. 5), were evaluated considering a single respiratory act.

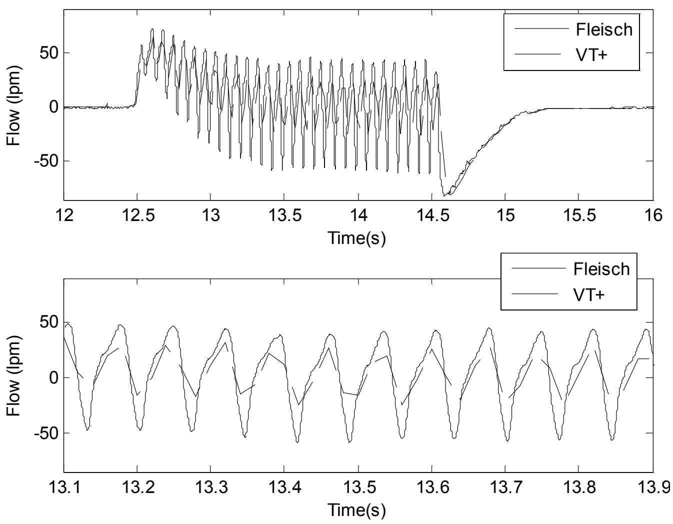

Fig.3 Flow behaviour along a single respiratory act (top) and a particular (bottom), acquired by means of our device (Fleisch) and the VT+ Gas Flow Analyzer.

From these figures it is evident that the sampling frequency of VT+ (50 Hz) is insufficient in the case of percussive ventilation and the volume evaluation generates an unacceptable error (Fig.5). On the contrary, the sampling frequency of our device (2 KHz) produces better results.

Therefore, for a correct assessment of the respiratory parameters and the volume exchanged in the high-frequency percussive ventilation, a measurement system with a wide bandwidth needs. This condition is not verified in current measurement systems of respiratory parameters which are not designed for monitoring respiratory values of such frequency range.

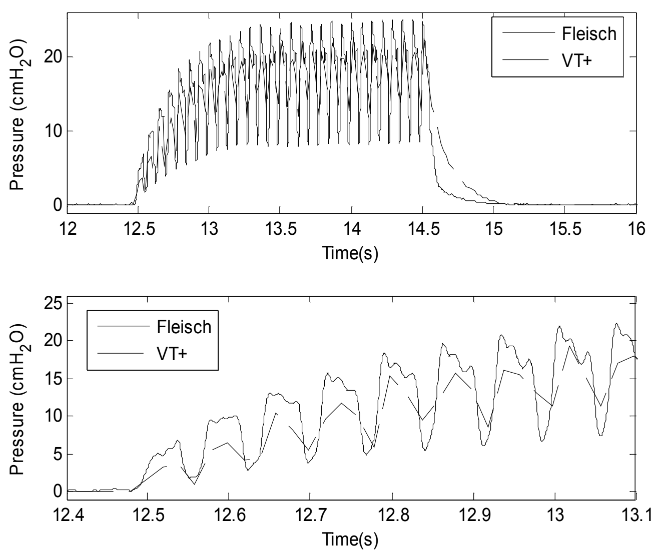

Fig.4 Pressure behaviour along a single respiratory act (top) and a particular (bottom), acquired by means of our device (Fleisch) and the VT+ Gas Flow Analyzer.

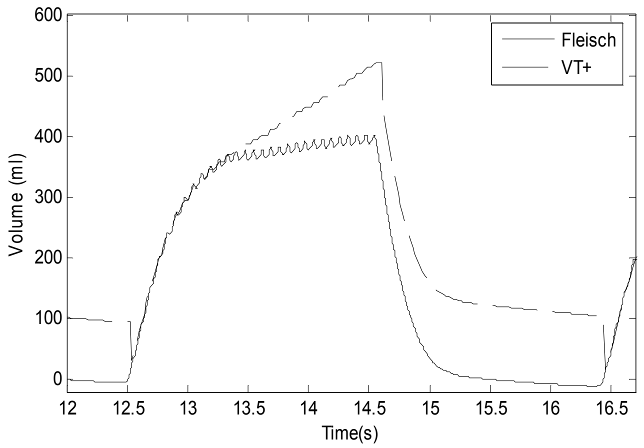

Fig.5 Volume behaviour obtained by integrating the flow signals of Fig.3.

IV. Conclusions

The results show that the proposed device is more reliable for measuring flow and pressure in high frequency band than commercial measurement systems of respiratory parameters.

The instrument is therefore able to realize a complete online characterization of high-frequency percussive ventilators in order to identify the best combination of their parameters according to the specific pathological situation like, for example, cystic fibrosis and distress respiratory syndromes.

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