Human breathing cycle simulation system, developed as additional functionality for thermal manikins

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Пневматична система, симулираща процеса на дишане при хората, създадена като допълнителна функционалност към топлинни манекени: *Настоящата публикация представя схемно решение на пневматична система, симулираща процеса на дишане при хората. Предложената система намира приложение при анализа и оценката на параметрите на микроклимата в затворените помещения, като допълнение към високотехнологичните топлинни манекени. Те представляват модерни инструменти, използвани за оценка на топлинния комфорт и усещането за качество на въздуха при обитателите на затворени помещения. Представената работа е част от дейностите по проект към НИС на ТУ-София, финансиран по направление „Перспективни ръководители“, с Договор № 151ПР0002-02, на тема: „Схемно решение за създаване на пневматична система, симулираща процеса на дишане при хората обитатели на затворени помещения“.*

Key words: *Indoor Environment, Indoor Air Quality, Thermal Manikins, Experimental Studies, Breathing Cycle;*

INTRODUCTION

In various scientific studies worldwide, it has been proven that all indoor environment parameters have significant influence over the occupants' health, comfort, productivity and performance [1, 6, 7]. That is why all the experimental studies in this area, conducted in laboratory or in filed conditions, have an extensive impact in improving the quality of life of people and the degree of their productivity and performance. And nowadays, the thermal manikins have very important place in these research studies [6, 7]. Considered as a distinctive complex research tools, the development of their functionality has particular importance for the entire field of environmental engineering science.

The thermal manikins are precise models of the human body, and are designed for analysis and assessment of the indoor environment parameters. They are used to study the free convection flow around the human body, in different conditions, without unnecessary exposure risk to the human occupants themselves [3, 4, 6]. In addition, thermal manikins are capable of simulating various processes related to human physiology, such as breathing, sweating, sneezing, coughing and others [6, 8].

But the experience with the recently developed breathing thermal manikins show that breathing functionality is quite an expensive and inflexible system and there is a need for further research and optimization in this area. One of the reasons is that all the additional functionalities, such as simulating breathing, sweating, sneezing and coughing, are complex systems external to the body of the manikins. Usually, the linking of the "nose" and the "mouth" of the manikins with these systems is implemented by multiple rubber hoses and extra wiring. This, and the very fact that the “breathing” system is outside the body of the manikin, significantly complicates the operation with these measurement devices [2,7].

AIM OF THE PRESENTED STUDY

The global aim of the presented study is to develop schematic solution for compact pneumatic system, which simulates the breathing cycle of human occupants in indoor environment. This system should be suitable for application as additional functionality in standard thermal manikins. In the presented paper, the following tasks are discussed:

- Review of the specifics of the respiratory cycle in humans, from a physiological point of view.
- Review of the general design parameters of the proposed pneumatic system.

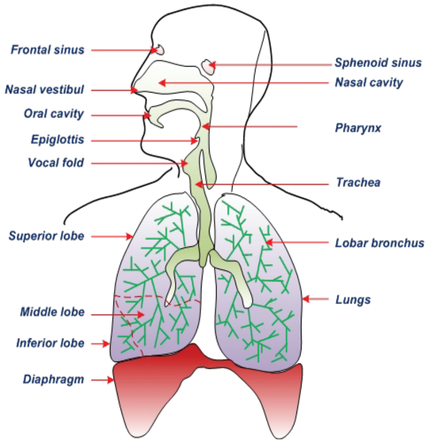
● Development of schematic solution for compact pneumatic system, simulating with high precision the respiratory cycle in humans.

BREATHING SYSTEM AND BREATHING CYCLE IN HUMANS

The main function of the human respiratory (breathing) system is to get oxygen into the human body and to take out waste gases [9]. The function itself is called “respiration” (breathing), and it is vital function of all living organisms. The human respiratory system is a group of organs working together to ensure the exchange of O2 and CO2 with the external environment. The lungs are basically the organs, which provide the gas exchange between the atmospheric air and the blood. The main components of the human respiratory system are shown schematically on Figure 1.

Breathing is considered to be the movement of air into and out of the lungs. Healthy adult human beings normally breathe 10 to 15 times per minute, depending on the activity level. Children breathe between 18 and 20 times per minute. During hard exercise, a professional athlete could breathe over 50 times per minute.

Simplified scheme of the human breathing cycle mechanism is also shown on Figure 1. The figure shows the possible lung volumes with respect to the time. The lungs of an average person have a “total lung capacity” of about 6 liters. But, only about 0.6 liters is exchanged during normal breathing. This volume is called the “tidal volume”. During exercise, deep breathing forces out much more of the total lung capacity and up to 4.5 liters of air can be inhaled or exhaled. This is called “vital capacity”. The vital capacity is always from 1 to 1.5 liters less than the total capacity because of the air trapped in the trachea and bronchi. This air is known as the “residual volume”.



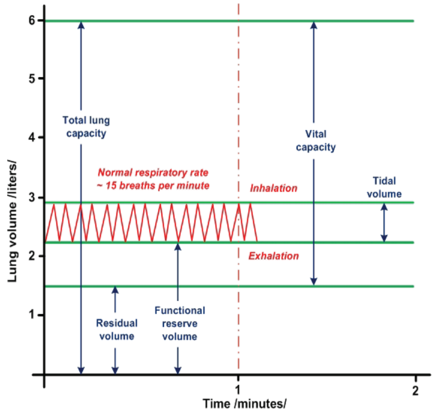


Figure 1 - Scheme of the human respiratory system and lungs volume change, with respect to time

DESIGN PARAMETERS OF THE PROPOSED PNEUMATIC SYSTEM

The surface area of typical thermal manikin is usually between 1.5 and 2 m^2, like the normal adult human being. The anthropometric measurements of real humans are used for external geometrical dimensions of all high precision thermal manikins. These measurements are taken and standardized for the different nations all over the world, and are usually used for design of clothing [2, 5]. That is why the overall geometrical dimensions of the presented pneumatic system are compact enough, to fit inside the body of a female thermal manikin model, based on the average Bulgarian woman size. Female model thermal manikins are mostly used for thermal comfort and clothing insulation measurements, because the ladies are more sensitive to the thermal environment changes and there is more variation in female than in male clothing. Another reason is that the female model is smaller and lighter and therefore it is easier to operate with.

The main design parameters of the proposed pneumatic system are:

● ***Overall geometrical dimensions:*** compact enough, to fit inside the body of a female thermal manikin model, based on the average Bulgarian woman size: 44 (Bulgarian system): 164 cm height, chest circumference 88 cm, waist circumference of 69.1 cm, hip circumference of 96 cm.

● ***Simulated total lung capacity, tidal volume and vital capacity:*** adjustable from 0 to maximum 3 liters. The simulated maximum lung capacity is restricted to ½ of the maximum real capacity, due to the space limitation. This capacity is suitable for applications where thermal manikins simulate light sedentary activities (office work) and also "sleeping". These activities by definition do not suggest a high degree of stress, accompanied by deep breathing. These are the most widely simulated cases in the indoor environment experimental studies.

● ***Frequency of the breathing cycle:*** adjustable from 1 to 60 breaths per minute.

● ***Breathing simulation***: the directions and the sequence of inhalation and exhalation (through the nostrils and/or the mouth) are entirely controllable.

● ***Simulation of sneezing and coughing***: the inhaled air is able to go out as quickly as possible, entirely controllable.

● ***"Sampling" function***: at certain time, the inhaled volume of air is redirected towards a gas analyzer system.

● ***Dosing CO2 or any other tracer gas:*** in order to use the thermal manikin as a pollution source.

SCHEME AND DESCRIPTION OF THE PROPOSED PNEUMATIC SYSTEM

The proposed compact pneumatic system is schematically presented on Figure 2. All used pneumatic elements are commercially available, except the main cylinder and piston mechanism.

The two small compressors “CS1” and “CS2”, which are driven by the step motor “StM”, accomplish the dosing of CO2 or other tracer gases through the system. The system allows the use of internal CO2 storage bottle “CO2A1”, controlled by the accumulator block “AB1” and the pressure sensor “PS2”. It also allows the use of external gas storage source, accomplished by the valve “V1”, controlled by the solenoid “S5”. The main compressor is equipped with pressure and temperature sensors, “PS1” and “TS1” respectively, which are used to ensure the correct operating conditions.

The main excessive volume compressor has a maximum volume of 3.5 liters and maximum working volume of 3 liters. The servo motor allows the main volume to be regulated, as well as the excess volume, but the excess volume cannot be less than 0.5 liters. The reason is that, a heater is situated in this volume. This heater is used to heat the “exhaled” air, and to ensure temperature of about 37 ^{o}C at the nostrils or mouth region.

In order to simulate realistic inhalation and exhalation, three proportional valves are used. Two of them simulate the nostrils, and one is for the manikin’s mouth. These proportional valves allow very precise control of the airflow through the nostrils. Also, after inhalation, no matter from where, the three proportional valves could be closed and at the beginning of the exhalation the discrete valve goes open. In that way, all the inhaled air is redirected towards external gas analyzer system. This function allows the thermal manikins to be successfully used in wide range of indoor air quality experimental studies.

The CO2 or other tracer gas dosing system is controlled by a step motor, connected to a double volume compressor. This allows two different tracer gases to be used during experiments, if it is needed.

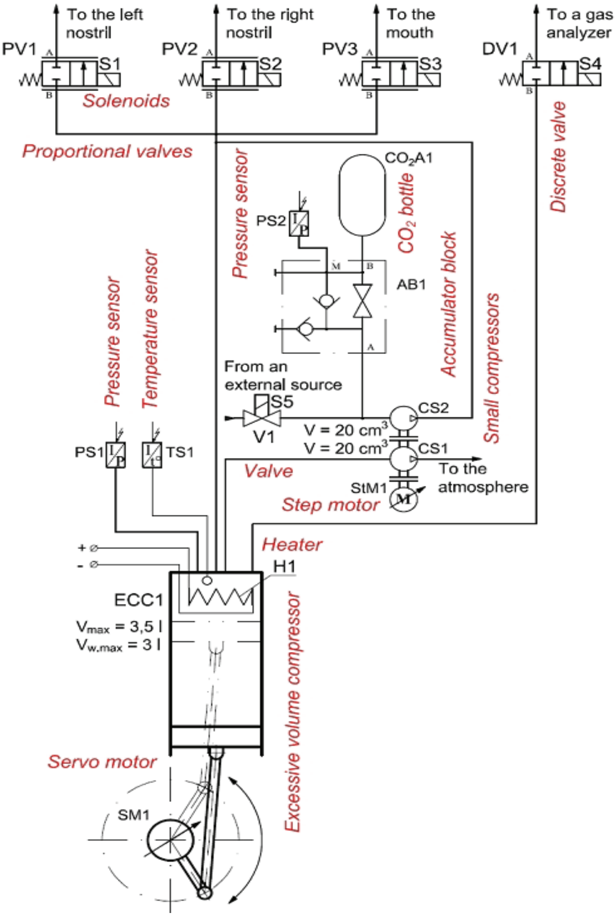


Figure 2 - Scheme of the proposed pneumatic system

The simulation of sneezing and coughing is preconditioned by the closing of all proportional and discrete valves. In that way, the pressure inside the main cylinder is increased to sufficient level, which will ensure the fast air release trough the nostrils and/or the mouth. The features of the entire system allow the sequence and the frequency of the sneezing and coughing to be completely controllable.

Obviously, the main cylinder and the piston are the devices with the biggest geometrical sizes in the suggested pneumatic system. If their size is decreased it will reflect to the simulated total lung capacity. Nevertheless, the presented system will still work properly, even if only the tidal volume of 0.6 liters is simulated, as it is during normal breathing. That way, the system will have the most compact overall dimensions. This will only limit the application of the thermal manikin, concerning the simulated activity level of the occupants.

CONCLUSION

● Pneumatic system, which simulates the breathing process in humans, is designed and presented schematically. This system works as additional functionality to the thermal manikins, which are used for analysis and assessment of the indoor environment parameters.

● The system allows controllable replication of total lung capacity, tidal volume and vital capacity, all of which may be adjusted from 0 to maximum 3 liters. The directions and the sequence of inhalation and exhalation are also controllable, and the breathing frequency can be adjusted from 1 to 60 breaths per minute. Further important features of the system are the “Sampling” mode, the sneezing and coughing simulation and the possibility of dosing CO2 or any other tracer gas.

● The described pneumatic system represents novel approach and will add significant value to the presented research area.

References

[1] ISO Standard 7730-2005, “Ergonomics of the thermal environment -- Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria”, International Organization for Standardization, 2005

[2] Bjørn E., „Simulation of human respiration with breathing thermal manikins“ Proc. of the 3rd inter. meet. on thermal manikin testing 3IMM, Sweden, 1999

[3] Ivanov M., Staykov D., Georgiev E., “Input parameters for development of pneumatic system, for simulating the breathing cycle of human occupants in indoor environment”, Proceedings of “XX International Scientific Conference FPEPM 2015 – Sozopol, Vol. 2, pp. 64-71 2015

[4] Ivanov M., Staykov D., Georgiev E., “Schematic solution of pneumatic system development, for simulating the breathing cycle of human occupants in indoor environment”, Proceedings of “XX International Scientific Conference FPEPM 2015 – Sozopol, Vol. 2, pp. 72-77 2015

[5] Madsen T., “Development of a breathing thermal manikin”, Proceedings of the 3rd international meeting on thermal manikin testing 3IMM, Stockholm, Sweden, 12–13 October, 1999

[6] Melikov A., "Breathing thermal manikins for indoor environment assessment: important characteristics and requirements". Europ. J. of Applied Physiology 92 (6): 710–713, 2004

[7] Melikov A., Kaczmarczyk J., Cygan L., “Indoor air quality assessment by a “breathing” thermal manikin. In: Awbi H (ed) Air distribution in rooms: proc. of Roomvent 2000, vol I. Elsevier, London, 101–106, 2000

[8] Tanabe S., Arens E., Bauman F., Zhang H., Madsen T., “Evaluating thermal environments by using a thermal manikin with controlled skin surface temperature”, ASHRAE Trans 100:39–48, 1994

[9] White I., “The respiratory system”, AS Biology, Module 1, Chapter 5 – “Breathing”, (www. biologymad . com, last visit: October.2015), October, 2005

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This paper has been reviewed.