Sizing and Simulation for Optimization of a Ventilation Installation Using Artificial Intelligence

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Abstract – In this article we present the way how to create a program in the Scilab-Xcos environment with which it can be dimensioned, mathematically modeled and simulated a ventilation installation using artificial intelligence for its implementation.

The mathematical equations implemented in the program with which the dimensioning and simulation are done are presented.

A neuro-fuzzy system was used to generate the fan characteristics.

Keywords – artificial intelligence, modelling, neuro-fuzzy, Scilab-Xcos, simulation, ventilation.

Nomenclature

Re – Reynolds number [-];
 v – speed of water circulation [m/s];
 ν – kinematic viscosity [m²/s];
 t – air temperature [°C];
 D – diameter of the pipe [m];
 λ – Darcy coefficient [-];
 k – the equivalent roughness of the pipe [m];
 M – the hydraulic resistance module [s²/m⁵];
 ξ – coefficient of local loss of hydraulic load [-];
 L – the length of the pipe [m];
 g – gravitational acceleration [m/s²];
 h_r – total hydraulic load loss [m];
 h_d – the loss distributed by the hydraulic load [m];
 h_l – local loss of hydraulic load [m];
 H_R – network load [m];
 H_s – static load [m];
 H_g – geodesic height [m];
 Q – air flow [m³/s];
 n_f – fan speed [rot./min.];
 Q_{PF} – the air flow at the point of energetic operation [m³/s];
 H_{PF} – the height at the point of energetic operation [m];
 P_{utila} – the fan power output [W];
 P – the power consumed by the fan [W];
 P_{ag} – the electrical power consumed by the aggregate [W];

η – the efficiency of the fan at the point of energetic operation [%];
 η_{mot} – engine efficiency [%];
 e_{sp} – specific energy [Wh/m³];
 ρ – air density [kg/m³];
 p – atmospheric air pressure depending on altitude [Pa];
 p_0 – atmospheric air pressure at sea level ($p_0=101325$ Pa) [Pa];
 R – universal gas constant ($R=8310$ J/kmol·K);
 T – gas temperature in degrees Kelvin ($T=273+t(^{\circ}\text{C})$);
 m – molar mass (for air $m=29$ kg/kmol);
 h – altitude [m];

1. INTRODUCTION

Nowadays, artificial intelligence is being used more and more often and in more and more fields to improve and increase the efficiency of the processes and systems in those fields.

The dimensioning and simulation for optimization of the ventilation installations especially industrial ones that have high electricity consumption is a topical thing in the context in which the emphasis is increasing on reducing the energy consumption, given that the energy resources (produced from hydrocarbons) of the land are limited [1].

In this article, a mathematical model was developed in Scilab-Xcos, which is used to size and simulate in order to optimize a ventilation installation using artificial intelligence, namely a neuro-fuzzy system to determine the fan characteristics.

Nowadays, fuzzy logic arouses a great interest from researchers, engineers and industry everywhere, but especially from all those who feel the need to formalize empirical methods, to generalize natural thinking modes, to automatize - in computer science sense - taking decisions in their field of activity, to build artificial systems to perform tasks that are usually performed by people [2].

The fuzzy set theory was developed in the United States of America in the early 1960s by mathematician Lotfi Zadeh, a professor at Berkeley University in California.

Fuzzy logic is a multipurpose logic, unlike Boole's logic which is bivalent (binary). The difference between classical logic, where it is rationed only in "all or nothing" mode and "fuzzy" logic, is that the latter takes into account a myriad of intermediate situations of the type: everything, much, medium, little, a little, nothing.

People's judgments are rarely binary, because the notions of "true" or "false" strictly appear only sometimes. Much more often the notions "maybe" and "more than true or false" are used.

Applications based on fuzzy logic were not possible until relatively recently, when the computing technique became performing and the fact that fuzzy logic requires more calculations than binary logic; it is no longer an obstacle in approaching applications [3].

A neuro-fuzzy network is a neural network that has the ability to process fuzzy information. In such a network, the input signals and / or the weights of the connections and / or outputs are fuzzy subsets or sets of values belonging to fuzzy sets. It is usually used as linguistic variable patterns, numbers or fuzzy intervals. The connection modules implement here the functions of a fuzzy system. A network performs the fuzzyfication of strict input data, the fuzzy rules are performed based on another network, and the defuzzyfication operation is performed by a third network to provide the strict output data. Networks with fuzzy neurons also fall into this category because they are capable of processing fuzzy information. These types of networks are useful in applications of fuzzy regression

(discovery of functional relationships between fuzzy data), control, solving fuzzy matrix equations (used in economics) or fuzzy classification [4].

Neuro-fuzzy systems represent a branch of artificial intelligence and can also be used in applications for approximating functions.

In this article, a neuro-fuzzy system was used to approximate the fan characteristics.

2. MATHEMATICAL MODEL

Knowing the flow rate Q required for ventilation and for the economic speeds v , is determined diameter D of the pipes of the ventilation installation.

With their help and using the relations below [5÷10], no. Reynolds Re , Darcy's coefficient λ (using Swamee's relation (1993) [8]) and hydraulic resistance module M are determined [1].

The diagram of a ventilation installation is shown in the figure below, fig. 1.

Fig. 1. Diagram of a ventilation installation

Also, depending on the temperature of the air conveyed by the ventilation system, the kinematic viscosity of the air ν is determined using equation (2) [9].

$$Re = \frac{v \cdot D}{\nu} \quad (1)$$

$$\nu = [14.66 + 0.096 \cdot (t - 10)] \cdot 10^{-6}, \quad (2)$$

for t between $10^{\circ}C$ si $30^{\circ}C$

$$\lambda = \left\{ \left(\frac{64}{Re} \right)^8 + 9.5 \cdot \left[\ln \left(\frac{k}{3.7 \cdot D} + \frac{5.74}{Re^{0.9}} \right) - \left(\frac{2500}{Re} \right)^6 \right]^{-16} \right\}^{0.125} \quad (3)$$

$$M = \left(\lambda \cdot \frac{L}{D} + \sum \zeta \right) \cdot \frac{8}{\pi^2 \cdot g \cdot D^4} \quad (4)$$

$$h_r = h_l + h_d = M \cdot Q^2 \quad (5)$$

Then the characteristic of the network is determined using the next relations [1, 5÷7]:

$$H_R = H_S + M \cdot Q^2 \quad (6)$$

$H_S=0$ (when the suction and discharge of the fan are done at atmospheric pressure).

The characteristic of the network $H_R(Q)$ was generated by the program realized in Scilab-Xcos (fig. 9) and is represented in fig. 5 [1].

Knowing the ventilation flow Q and the ventilation height H the fan is chosen. The ventilation height H is determined by calculating the local and linear load losses (for long pipe sections the local load losses are neglected) [1].

A few points are mentioned on the Q-H catalog feature (eg SAVEB V28S 1600/1630 fan, $n = 750$ rpm) [18], of the chosen fan (fig. 2), with the help of neuro-fuzzy system and using Scilab the sciFLT and anfis toolboxes, the Q-H feature of the fan is realized (fig. 4), which the operation mode of the ventilation installation is simulated.

Fig. 2. The catalog characteristics of the fan for which the simulation is performed [18]

Fig. 3. The points read on the Q-H characteristic curve of the fan supplied by the manufacturer

Fig. 4. Console with training data read on the characteristic Q-H curve of the fan (represented in blue) and validated data generated by the ANFIS application in Scilab (represented in red).

Also, using the similarity relations [1, 5÷7], the characteristic curves of the fan for its different speeds are determined.

$$\frac{Q_1}{Q_n} = \frac{n_1}{n_n} \quad (7)$$

$$\frac{H_1}{H_n} = \left(\frac{n_1}{n_n} \right)^2 \quad (8)$$

This can be seen in the figure below (fig. 5).

Fig. 5. The characteristic curves of the fan $H(Q)$ for various speeds (750, 700, 650 rotations / minute) realized with neuro-fuzzy system and the characteristic curve of the $HR(Q)$ network, generated by the program realized in Scilab-Xcos

For the H_{PF} and Q_{PF} values of the operating point of the installation and using the relations (9÷14), the following parameters are calculated [1, 5÷7]:

- The fan power output

$$P_{utila} = \rho \cdot g \cdot Q_{PF} \cdot H_{PF} \quad (9)$$

- Power consumed by the fan

$$P = \frac{\rho \cdot g \cdot Q_{PF} \cdot H_{PF}}{\eta} \quad (10)$$

- The electrical power consumed by the aggregate

$$P_{ag} = \frac{\rho \cdot g \cdot Q_{PF} \cdot H_{PF}}{\eta \cdot \eta_{mot}} \quad (11)$$

- Specific energy of the aggregate

$$e_{sp} = \frac{P_{ag}}{Q_{PF}} \quad (12)$$

We used relation (13) to determine air density as a function of temperature and atmospheric pressure [19] and relation (14) to determine atmospheric air pressure as a function of altitude [19].

$$\rho = \frac{p \cdot m}{R \cdot T} \quad (13)$$

$$p = p_0 \cdot e^{\frac{m \cdot g \cdot h}{R \cdot T}} \quad (14)$$

Fig. 6. The points read on the characteristic Q - η curve of the fan used to generate the characteristic with neuro-fuzzy system

The Q - η characteristic of the fan (fig.7) was generated using neuro-fuzzy system, reading a few points on the fan's performance characteristic of fig. 2, provided by the manufacturer [18].

Fig. 7. Console with training data read on the characteristic Q - η curve of the fan (represented in blue) and validated data generated by the ANFIS application in Scilab (represented in red)

For the operating flow of the QF ventilation installation, the fan efficiency, used in the energetic calculations of the installation was read on the Q - η characteristic (fig 8)

Fig. 8. The characteristic yield curve of the η (Q) fan achieved with neuro-fuzzy system in Scilab-Xcos

All these mathematical relations were implemented in the program realized in the Scilab-Xcos environment (fig. 9), which allows the simulation of a ventilation installation [1].

Fig. 9. The scheme developed in Scilab-Xcos, which allows the simulation of equipment sizing and air ventilation installation

Scilab-Xcos environment has a free license. The program being realized in this environment, allows the immediate implementation, without costs in the ventilation systems. By making simulations with its help, the ventilation systems can be made more efficient [1].

This program is also useful to specialists working in the design of ventilation systems and those who carry out mathematical modeling and simulation programs.

The program allows a wide spectrum of simulations of a ventilation installation, including the limit situations in which for various water temperatures the ventilation installation operates cavitationaly, thus avoiding this mode of operation from the design stage.

Also, this program can be very easily implemented in the Matlab-Simulink environment [1].

3. SIMULATION EXEMPLE

The following is an example of a simulation starting from the following input data:

- The air flow required to be ventilated $Q=40 \text{ m}^3/\text{s}$;
- Pipe diameter $D=1.8 \text{ m}$;
- Pipe length $L=50 \text{ m}$;
- Air temperature $t=12 \text{ }^\circ\text{C}$;
- Altitude $h=100 \text{ m}$;
- Atmospheric air pressure at sea level $p_0=101325 \text{ Pa}$;
- The sum of the local load loss coefficients $\Sigma\xi=10$;
- The efficiency of the electric motor fan drive $\eta_{\text{mot}}=0.89$;
- Equivalent roughness of the pipe $k = 0.00015 \text{ m}$;
- Gravitational acceleration $g = 9.81 \text{ m/s}^2$;
- The characteristics of the fan in fig. 2 approximated with the openwork of neuro-fuzzy systems.

All these data were entered in the program as in fig. 9, with the help of which the ventilation installation was simulated.

The simulation resulted in the values of the following parameters:

- Kinematic viscosity $\nu=0.00001485 \text{ m}^2/\text{s}$;
- Reynolds number $Re=1905077.6$;
- Darcy's coefficient $\lambda=0.0126$;
- Hydraulic resistance module $M=0.08 \text{ s}^2/\text{m}^5$;
- Atmospheric pressure $p_{\text{atm}}=100115.149 \text{ Pa}$;
- Air density $\rho=1,226 \text{ kg/m}^3$;
- The fan power output $P_u=86.18 \text{ W}$;
- Power consumed by the fan $P=104.46 \text{ W}$;
- The electrical power consumed by the aggregate $P_{\text{ag}}=117,371 \text{ W}$;
- Specific energy $e=2,637 \text{ Wh/m}^3$;
- The graphs of fig. 5 and 8.

4. CONCLUSIONS

This article presented how to create a program, for which was used the artificial intelligence, namely neuro-fuzzy systems. The program allows sizing, mathematical modeling and simulation of a ventilation installation.

The neuro-fuzzy systems used to approximate the characteristics of the fans have the advantage as seen in this article that they approximate exactly the manufacturer's characteristics of the fans, while if they were approximated with a polynomial function of degree 2 there were differences, sometimes quite large.

This program was developed in Scilab-Xcos environment, uses neuro-fuzzy system for generating the fan characteristics and has a wide spectrum of application, being able to make simulations for generating the fan characteristics and for its different speeds.

Simulations can also be made for variations of the air temperature conveyed by the ventilation system. It can also be used to simulate the transport of other gas such as natural gas transpotation. The program has immediate applicability and is recommended to designers, specialists in the field and all those interested.

5. REFERENCES

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Note:

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