MULTIPLE MODEL CONTROL SOLUTION FOR SERIES FANS PROCESSES (WITH VARIABLE LOAD)

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In the paper, a solution for series multiple fan systems control is presented. Their applicability in modern building or mine ventilation systems is obvious. In order to validate the proposed solution an experimental stand and a real time software have been developed. The control algorithm is based on three multiple models system configurations, each one consisting in three operating systems, specific to the experimental stand.

Keywords: real time, multiple model, variable loads, multiple fan

1. Introduction

Fans are used in industrial and commercial applications on a large scale. Fan functioning is essential also in heating and cooling systems to maintain a satisfactory working environment [1]. Fan failure or malfunction in inaccurate parameters will lead to lower productivity and respectively to a lower product quality. This is available for some production applications where air purity is essential for minimizing production defects (manufacturing electronic components by injection molding).

2. Controlling Fans with Variable Loads

Fans are often used over a wide range of operating conditions. Industrial ventilation systems face variable loads because of different changes (environment conditions, occupancy, production demands). For demand changes, flow is controlled by three main methods: inlet vanes, outlet dampers, and fan speed control.

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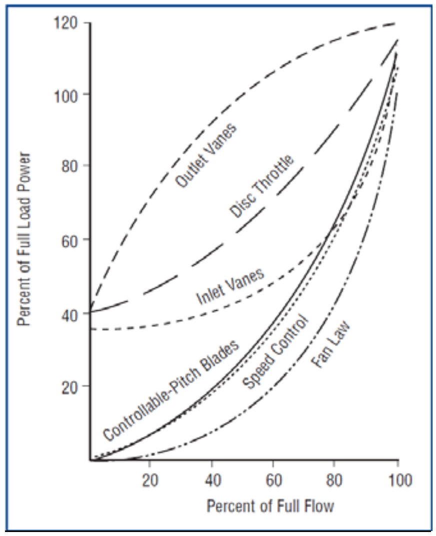

Fig.1 Relative Power Consumption among Flow Control Options [1]

These methods have advantages but also disadvantages because of initial cost, flow control effectiveness, and energy efficiency. There are fan systems used infrequently (less than 500 hours/year) and their initial cost may be the most important factor. In high run-time applications, flow control effectiveness and energy efficiency may determine their usage.

Fans must operate for extended periods in many industrial applications. They are often used directly to support production (material handling) or to maintain proper working conditions (ventilation). Fan system efficiency in operation is very important in both cases. Flow control options and their relative efficiencies are shown in Fig.1.

3. Multiple Fan Configuration

When a fan (of a system) can not supply a sufficient (fluid) flow to provide the necessary cooling level and the physical size of the enclosure doesn't fit a larger fan, a system of fans configured in series or in parallel is required. Many times, two smaller fans are less expensive and offer better performance than a larger one. In the case of two series fans configuration, they can double the fluid flow when functioning outside because no pressure comes back to limit the air flow. This is a theoretical case that is not to be found practically. Fans that operate outside can generate possible maximum flows, and, when installed inside, they must overcome the air flow resistence. To do this, the fan must produce an increased pressure which will lead to a lower air flow.

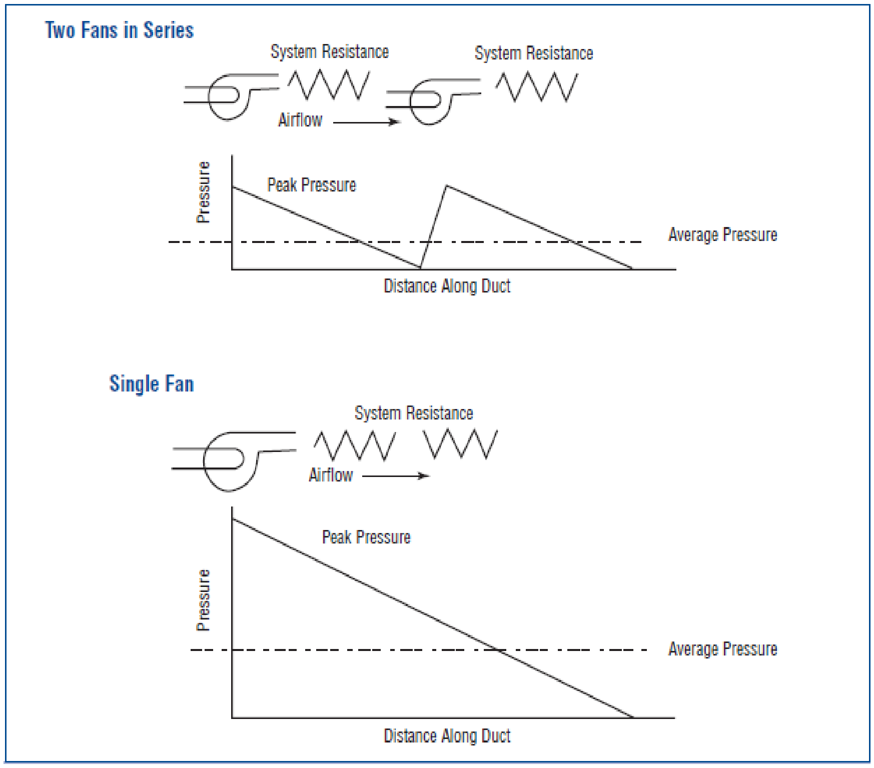

Fig.2 Lower Duct Pressure Because of Fans Placed in Series [1]

Advantages of series disposing fans are many, such as: lower average duct pressure, lower structural and electrical support requirements, lower noise generation.

As shown in Fig. 2, the series-configurations fans along different points in a system minimize the average static pressure in a duct. Because leakage in a duct system depends largely on the difference between the system inside and outside pressure shall minimize system leaks energy losses.

Closed loop control design for simple flow and pressure process are well known in current engineering practice and scientific literature [2], [3]. However, series / parallel multiple fans arrangement determine a lot of practical problems like increased instability zones, nonlinearity and others specific problems [1].

Taking into account the behavior of series fans configuration, the design of a control system for real time applications imposes some special structures like adaptive, robust etc. solutions [4].

Multiple model or multicontroller structure, as direct adaptive structure [4], can represent a valuable solution used to maintain the performances in the case of some uncertainties, structural disturbances or non-linearities. In next section this kind of solution will be basically presented.

4. Multiple model control solution

As presented in [5-7] the solution of multiple model control means choosing a set of models *M*, and a set of corresponding controllers, *C*:

$$M = \{\mathcal{M}_1, \mathcal{M}_2, \mathcal{M}_3 \ldots \mathcal{M}_n\}$$
$$C = \{C_1, C_2, C_3 \ldots C_n\} \tag{1}$$

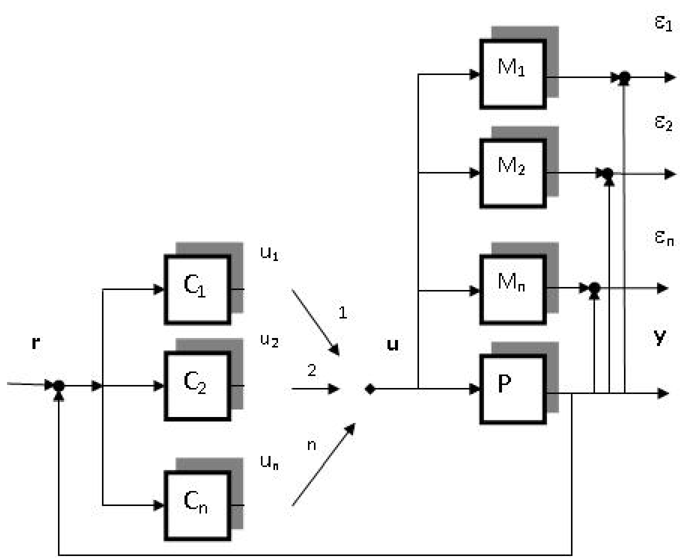

Fig. 3. Multiple model control structure [2]

Based on this model/controller (*M/C*) pair, a closed loop configuration is presented in Fig. 3. The process *P* input and output are u and respectively *y*; *r* is the reference variable of the system. The M_i models ($i = 1, 2, \ldots n$) are a priori determined. For each M_i model, a controller C_i is designed that ensures the nominal performances for the (M_i, C_i) pair.

During real time functioning the most adequate C_i controller is chosen and the corresponding command is calculated and suppplied to the real proces. Some specific problems about multiple models, like best controller selection and algorithm! switching are presented and solved in [6], [7].

5. Tests and experiments for multiple fan configuration

An experimental and flexible stand and a software application based on multiple model architectures have been implemented in order to develop and validate in real time the leading solutions of the process using multiple fans.

5.1. Hardware and software structure description

The main idea of the experimental stand is to offer a versatile platform for testing the structures with multiple fans arranged in series and/or in parallel. The main component parts are axial fans, pressure and flow sensors, drivers and signal adapters (for sensors and fans) and different pipe profiles. The fans and the sensors are specially adapted to be fast connected to auxiliary pipes and elements.

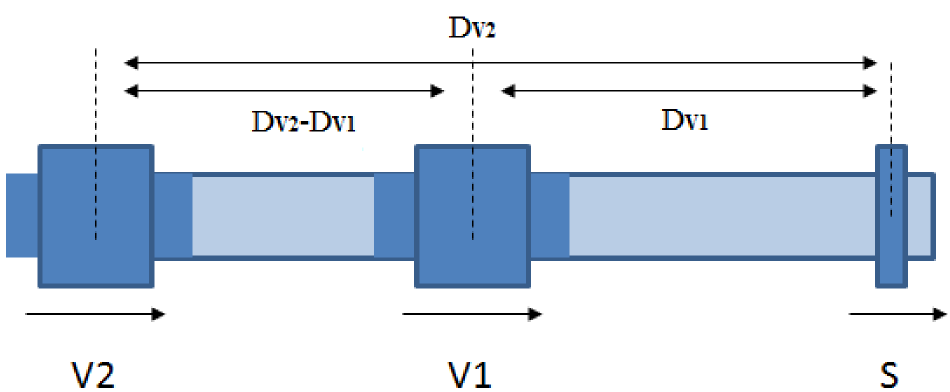

Fig. 4. The experimental system structure

The connection and the control of a stand is made by some data acquisition systems (e.g. NI USB 6008) or by means of PLC. Software applications can be developed in specific or general languages, from CScape (Horner TM), RS Logix (Rockwell Automation) to Lab View and LabWindows CVI (National Instruments) [10] or Matlab/Simulink (MathWorks) [12].

The used structure for the current experiment contains two axial fans arranged in series (V1, V2) and a flow/ pressure sensor (S) (Fig. 4).

The two fans have variable speed. The acquisition and the control are made by an acquisition system NI USB 6008. The software application that implements the adjustment algorithms and the SCADA [11] system is developed in the Lab Windows CVI (National Instruments) environment.

5.2. Conditions and functional domains of the stand

As we have noticed, also, in the introduction, the disposing in series of the fans is useful for the pressure required or distance to which the useful fluid quantity is sent; there are, also, specific advantages presented in the subchapter. The domains of use for the configuration in figure 1 are presented in the Table 1.

V1 and V2 fans can be set ON or OFF, and when they are ON, they can function to a fixed rotation (FIX) or a variable rotation (VAR) in a specific game. We can notice the last variant from the table is that where V1 and V2 work in a variable range from 0% to 100%. Although it seems the clearest and the most advantageous, it is not always possible because, in many situations, it is required a minimal fluid flow, that must be ensured. It can be produced by the two fans functioning continuously or by a single one, no matter which. For efficiency and safety reasons it is preferable to use a single element (V2) that has a fixed speed (for ex. de 20%). This situation can be identified in the third line of the table.

Table 1

The functional domains of the component parts

Nr. Exp.	State V1 / range power	State V2 / range power	Variation domain pressure
1	OFF	ON / VAR 0-100%	0-2.5%
2	ON / VAR 0-100%	OFF	0-16%
3	ON / FIX 20%	ON / FIX 20%	20%
4	ON / VAR 0-100%	ON / FIX 20%	0-40%
5	ON / VAR 0-100%	ON / FIX 40%	0-55%
6	ON / VAR 0-100%	ON / FIX 100%	25-100%
7	ON / VAR 0-100%	ON / VAR 0-100%	0-100%

In the Table 1, it can be noticed too, that using a single fan can lead to a specific domain of the flow / pressure variation, the highest value being identified in the second experiment. It became obvious that the variation domain of the useful parameter (pressure) diminishes when the distance between the pressure sensor and the fan increases.

In the control of the system there one can distinguish three situations, two major ones and a third, derived from the first two:

a) (VAR-FIX) V1 in variable range and V2 in fixed range;
b) (VAR-VAR) V1 and V2 in variable range;
c) (VAR-VAR/FIX) Combinations of the situations a) and b) on different function domains.

It is to be taken into consideration the fact that an inverter may be necessary to get a variable range for the respective fan, but this solution is more expensive. The alternative of the variable checking by an inverter is that of a constant function range to specified fixed rotations.

The major advantage of the variable rotation is low energy consumption. However, from the point of view of the performances of control systems, for certain specific instability points of the process (the control process for the pressure/flow) the use of at least a single fan in fixed range (V2 in our case) can increase the stability of the solution.

5.3. Control solution for a fixed speed fans structure (VAR-FIX)

In the next section, two solutions corresponding to the a) and c) situations previously presented, will be tested. For option (a) the use of three functional conditions for the process are proposed as presented in Table 2.

The variation interval of V1 on the three domains are maximum 0-100%, but practically, for the experimental stand they are approximately 0-50% - domain 1, 40-60% - domain 2 and respectively, 50-85% - domain 3. These are dependent on the fans parameters, the distances between the fans, the distances between fans and sensors (dV1, dV2, dV1-V2) etc. The Table 1 presents some of these situations.

Table 2

Functional domains

Domain number	State V1 / range power	State V2 / range power	Variation domain pressure
1	ON / VAR 0-100%	ON / FIX 20%	0-30%
2	ON / VAR 0-100%	ON / FIX 60%	30-60%
3	ON / VAR 0-100%	ON / FIX 85%	60-100%

In conclusion, the domain 1(d1 - 0-30%) is ensured by V2 functioning to a fixed rotation (20%) and by V1 variable in the domain 0-50%. The domain 2 (d2 - 30-60%) is ensured by V2 functioning to a fixed rotation (60%) and by V1 variable in the domain 40-60%. The last domain 3, (d3 - 60-100%) is ensured by V2 functioning to a fixed power (85%) and by V1 variable in the 50-100% domain. This function recommends the use of a multiple model structure having at least three domains.

As we can notice, the “demarcation” limits between the three domains are 30% and respectively, 60%. The structure of the implemented multiple model algorithms is presented in [5] and Fig.ure 3.

The control algorithms design has been made by experimental techniques [2], [3] and they lead to the use of simple algorithms, of type PI or PID, where the parameter values of the three algorithms are presented in Table 3:

Table 3

The adjustment of the parameters

Domain number	Kr	Ti	Td
1	0.75	5.0	0
2	0.9	5.5	0
3	0.8	6.0	0

It is noticeable that the algorithms are simple, having the integration constant (Ti) of a close value, the difference being recorded from the point of view of the proportionality constant (Kr). However, because the use of some very simple algorithms (PI) was "forced", the differences of the parameters are essential in their behavior on the corresponding domain.

The used colors in the diagram are the following: yellow - set point; green- filtrate set point; red - the command of the active algorithm; blue - the adjusted pressure evolution.

The real time evolutions are presented in Fig. 5.

It is noticeable that the evolutions in real time are stable, following the set point without problems. The evolutions in the center and in the right side include also the "shock" due to the change of the functional conditions. This is more perceptible only in the right side diagram, but it is not disturbing.

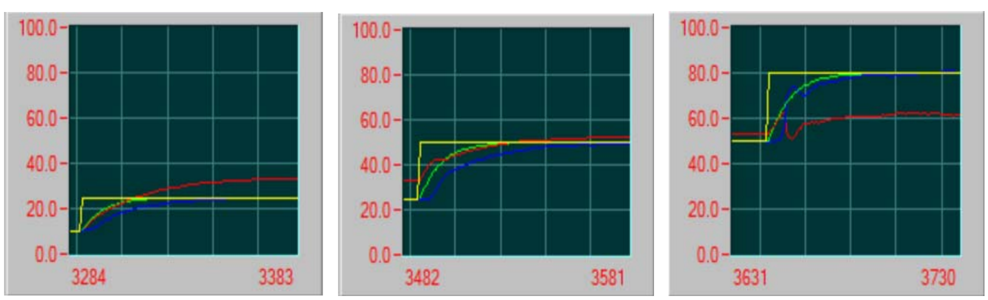

Fig. 5. The real time evolution of the proposed multiple model system for the situation where a fan has a fixed power, corresponding to the domain, and the other has a variable power (VAR-FIX): left) evolution in the functional domain 1; center) evolution in the functional domain 2; right) evolution in the functional domain 3.

5.4. Control solution for a structure based on a mixed solution (VAR-VAR/FIX)

The second experiment aims to solve some sensible problems occuring when more fans are functioning, more precisely the instability areas. For this process, it has come out that around the value 60 % there is an area where hysteresis phenomena are occuring. This non-linearity creates obvious problems to some classic algorithms imposing specific solutions [8], [9].

We have chosen, as a practical solution, the "isolation" of the respective interval by using a "calm" adjustment algorithm, having special performances so that it would not create powerful variations of the command. Clearly, some performances such as the rejection speed of the disturbances have been sacrified. Thus, the second solution presented takes into consideration using a (VAR-VAR) solution for the domains 1 and 3 and of a (VAR-FIX) solution for the domain 2. Table 4 synthetically presents this structure.

Table 4

Functional domains

Domain number	State V1 / range power	State V2 / range power	Variation domain pressure
1	ON / VAR 0-100%	ON / VAR 0-100%	0-55%
2	ON / VAR 0-100%	ON / FIX 60%	55-65%
3	ON / VAR 0-100%	ON / VAR 0-100%	65-100%

As it can be noticed, the "demarcation" limits between the three domains are 55% and respectively, 60%.

As in the first case, the variation intervals of V1 on the three domains are considered maximum 0-100%, but practically, for the experimental stand, they are approximately 0-58% - domain 1, 55-65% - domain 2 and respectively, 60-85% - domain 3. Here it is also recommended to use a multiple model structure having at least three controllers.

The control algorithms design has been made here also by experimental techniques that lead to the use of simple algorithms, such as PI or PID, where the parameter values of the three algorithms are presented in Table 5:

Table 5

The adjustment of the parameters

Domain number	Kr	Ti	Td
1	0.75	5.0	0
2	0.5	8.0	0.05
3	0.8	6.0	0

The evolutions in real time are presented in the following diagrams (Fig. 6)

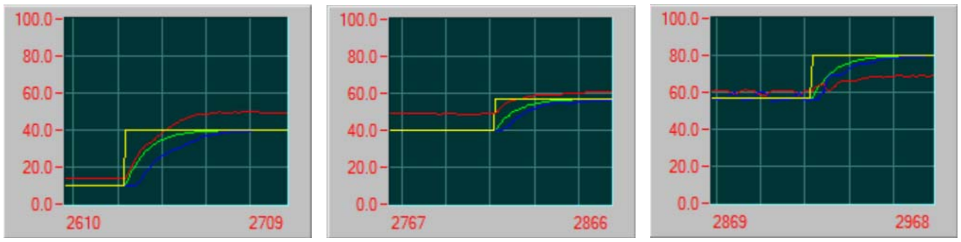

Fig. 6. The evolution in real time of the proposed multiple model system for the situation (VAR-FIX): left) evolution in the functional domain 1; center) evolution in the functional domain 2; right) evolution in the functional domain 3.

The colors used in the diagrams are the same as those previously mentioned (Fig. 5). Also, in this situation, the real time evolutions are stable, the set point being correctly followed . The evolutions in the center and in the right side include the change of the functional conditions. Its "shock" is perceptible only in the right side diagram, but it is much reduced.

5.5. Comparative analysis of the structures (VAR-FIX) vs. (VAR-VAR/FIX)

Generally, the performances of the two solutions are almost the same, the second one is "calmer" from the point of view of the command evolution; but these aspects are strictly connected to the physical structure of the system.

An interesting analysis can be made from the point of view of the power consumed by the two fans (Table 6).

Table 6

The power distribution of the two fans

Ref	V1 VAR-FIX	V2 VAR-FIX	V1 VAR-VAR/FIX	V2 VAR-VAR/FIX	S1=V1+V2 VAR-FIX	S2=V1+V2 VAR-VAR/FIX	D = S1-S2
10	11	20	12	12	31	24	7
20	25	20	23	23	45	46	-1
30	48	20	36	36	68	72	-4
40	42	60	50	50	102	100	2
50	52	60	56	56	112	112	0
60	60	60	58	60	120	118	2
70	52	85	62	62	137	124	13
80	61	85	70	70	146	140	6
90	71	85	78	78	156	156	0
100	82	85	84	84	167	168	-1
Summ							**24**

The values presented in the table were obtained by the functioning of the application in real time. The first column (Ref) represents the set point value and implicitly the adjusted pressure. The columns V1 and V2, either are bound to the functions (VAR-FIX) or (VAR-VAR/FIX) represent the commands received by the two fans.

The sums S1 and S2 gather the powers on V1 and V2, and D = S1-S2.

It is important to notice that the added values of D column lead to a positive value (24), non-dimensional(%), in the case of the experiment which may represent an important argument to support the second alternative, more economical than the first one.

Clearly, this analysis can be moderated by the "using time" factor in a certain area, that can give a more correct image of the adequate solution (VAR-FIX), (VAR-VAR) or (VAR-VAR/FIX).

5.6. Experimental stand

The main elements of the experimental stand are: physical process, acquisition system, fans drivers and power supply (Fig. 7).

The physical process is the one presented in the subchapter 5.1 (Fig. 4) and contains the two axial fans V1 and V2, the pressure sensor S and the connection pipes.

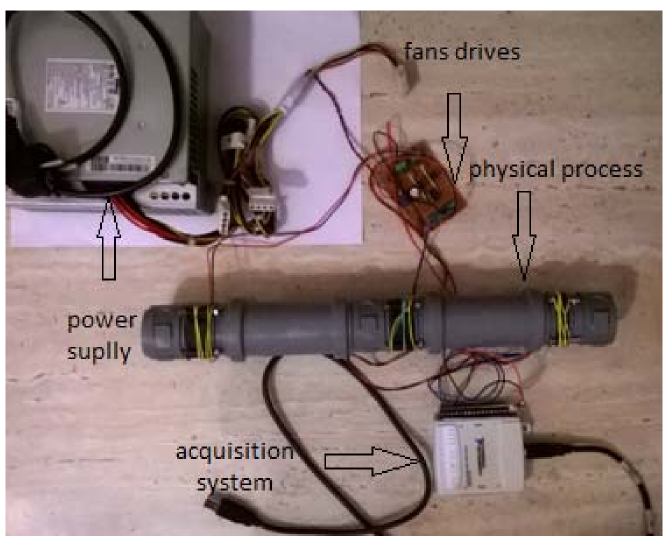

Fig. 7. Experimental stand

The acquisition system is of NI USB 6008 type from where the two analogical outputs were used (AO0 and AO1) for the fans command and one analogical input (AI0) for the pressure value acquisition. The system is connected to an USB port of the PC or the hardware system where the software application is implemented.

The fan drivers replace the frequency converters in order to provide fans variable speed/power. This module is necessary because the USB acquisition system output can provide a maximum of 5 V amplitude and very little power in comparison to the one necessary for the fans. The PC type power source provides the necessary energy for the process and drivers.

5.7. Software application

The software application was made in LabWindows CVI from National Instruments environment [10]. This application implements in real time mainly the multiple model control algorithms with three different conditions. Fig. 8 presents the main window of the algorithm.

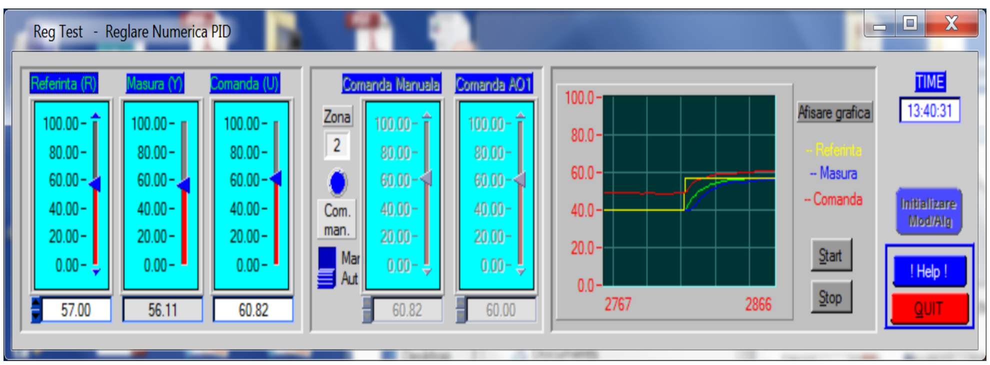

Fig. 8. Software application – the main screen

The (SCADA) facilities offered are the following:

- real time display (numerical and graphical) of the main parameters of the process (set point, process value, command);
- possibility of setting a distinct manual command on the fans;
- possibility of setting the system set point;
- changing the adjustment algorithm manually/automatically;
- opening a parameter configuration window.

The configuration window of the application (presented in Fig. 9) offers the following facilities:

- configuration of data acquisition (sampling period, numerical filter, AI and AO variation domains etc.);

- configuration of control algorithms (Kr, Ti, Td, set point filter);
- configuration of multiple model control structure (limits of domains, VAR-VAR function selection etc;
- loading a basic configuration from an extern file.

From this screen the functioning of the application is very large, having the possibility to be also used with other physical processes, by modifying only the corresponding values. The main idea of the development was to offer the user the possibility to modify the experimental stand without being forced to modify the software application as well.

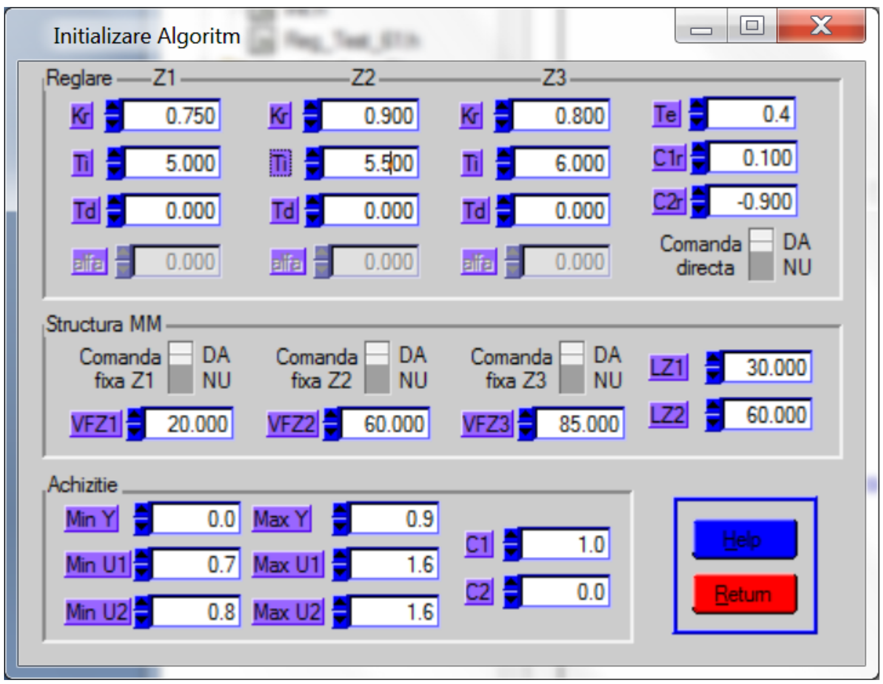

Fig. 9. Software application - the configuration screen

6. Conclusions

In this paper, a solution for series multiple fan systems control is presented. Their applicability in modern building or mine ventilation systems is obvious. In order to validate the proposed solution an experimental stand and a real time software have been developed. The control algorithm is based on three multiple model system configurations, each one consisting in three operating systems, specific to the experimental stand.

The experimental results validate the proposed solution and leed to interesting conclusions.

Acknowledgement

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