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Using of Fuzzy Logic in Technical Expertise of Refrigeration Installations of Cold Chambers

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Abstract: In this research, we have presented a software for technical expertise of refrigeration installations of cold chambers. This software is developed on the base of fuzzy logic and intended for a general use, contrary to those implemented currently for specific installations, in the maintenance systems or those of remote monitoring. The expertise here is done in three stages: recalculation of the installations, internal diagnosis and decision-making. The objective of a general use have been achieved by the implementation of suitable techniques of artificial intelligence, in particular a genetic algorithm for the diagnosis and a fuzzy rules system for the decision-making. In addition, user libraries called FCC (Fluidic Circuit Configuration) allow the taking into account of various configurations of refrigerating installations. This software was developed for windows and its evaluation on a cold store of 10000 m^3 showed that it fulfils indeed its function.

Key words: Software, expertise, fuzzy logic, redimensioning, internal diagnosis, decision-making

INTRODUCTION

A cold chamber is an enclosure inside which is created favourable artificial climatic conditions for the conservation of given products. These conditions are created by refrigerating installations and their stability is of primary importance to ensure a good quality to the preserved products (Gac and Gautherin, 1987). From there it arises that the maintenance of these refrigerating installations is a great stake.

In order to ensure a good reliability to the refrigerating equipments, a conditional preventive maintenance is generally implemented (Nkamtchoumi, 1988). It will consist of following operational parameters (pressures, temperatures, sound levels...), in order to sufficiently early detect the failures, which are generally by degradation. In this approach a good knowledge of the installations is required, especially when appear failures modes difficult to be explained. Computers can then provide an important help, by offering automatic expertise functionalities.

The goal of technical expertise of a failed equipment in a general way is to detect the causes of the failure (it is the diagnosis) and to propose remedies (Monchy, 2000). The currently available computer tools for this task on refrigerating installations are those associated with the maintenance systems or those of remote monitoring (Chevalier, 1986). But in all these cases, they are intended for specific installations and thus often developed on request. For companies having a park of installations of varied technologies and builders, these solutions are quickly very expensive. It is very often the case in the developing countries. An interesting solution in this case would be to have expertise soft wares which are cheap and for a general use.

In the process of automatic expertise, it is the phase of diagnosis which is most delicate. There it will be a question of reversing a relation of cause to effect. To reach that point there are currently two great families of automatic diagnosis techniques (Zwingelstein, 1995):

- Methods of external diagnosis, requiring an initial human expertise or a solid databank of feedback experience. Here there are for example pattern recognition systems or expert systems:
- Methods of internal diagnosis, where the relation of cause to effect is defined by a physical or experimental model of simulation of the equipment. When this model is not defined explicitly but rather in an algorithmic way, then the inversion of the relation could be done using nondeterministic techniques such as simulated annealing or genetic algorithms.

After diagnosis, the automatic proposal for remedies can effectively be implemented by a rules based system. The principal problem to be solved here is that of the

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transposition and the processing of the human knowledge. That is why the use of traditional expert systems-using the boolean logic - in the industry has been limited (Zwingelstain, 1995). The fuzzy logic is a good solution to this problem, because it allows the taking into account of vague and not precise concepts specific to our language (Tong, 1995).

In this research we developed a software for technical expertise intended for a general use. Here, two principal difficulties are to be surmounted:

Specificities of the installations: The expertise must be valid for any type of installations, with all its specificities (configuration of the fluidic circuit, available points of measurements, constructive characteristics, technologies used).

The evolutionarity of the software: The program package should not be limited to given types of installations. It must be able to include new types without recompiling of the codes.

The first problem is solved by the implementation of an adapted way of appraisal and the second by the design of a changing architecture for the software.

SOFTWARE ANALYSIS

Global analysis

Principle of the expertise: The principle of expertise we retained is centred on the following points:

- Thermal balance of the cold room to be appraised, using exploitation data.
- Diagnosis of the refrigeration installations, based taken measurements, in order to get the real state of the installation.
- Recalculation of the installations on the basis of heat balance, in order to obtain the nominal state of the equipment.
- Decision making, using the results of the preceding phases, by comparison of the nominal and real states of the installation.

The state of a given refrigeration installation is represent here by a set of external parameters-accessible by measurements-and a set of internal parameters-accessible by measurements.

Modular architecture: The software is made of four main modules:

- Module of calculation of heat balance.
- Module of internal diagnosis.
- Module of recalculation of the refrigeration installation.
- Module of the final decision-making.

Detailed analysis

Module of calculation of heat balance: For each compartment of the cold chamber, this module must provide:

- The conservation temperature to be obtained.
- Relative humidity to be maintained.
- Refrigerating power to provide by the evaporators for a given daily operating time of the installations.

For that purpose, the user must be able to enter in a convivial way the data necessary. It is:

- Geometrical and dimensional parameters.
- Parameters related to the constitution of the walls and the floor.
- Climatic data of the place;
- Exploitation data of the cold room.

We synthesized the climatic data under the name of climatic profiles. A project of expertise is related to a given climatic profile includes in the software and the user can of course add his own profiles.

The calculations carried out in the program package are based on the formulas and correlations indicated in Kane and Schoenauer (1997).

This stage, it arises already that the data to be acquired are significant and that it is thus advisable to take a particular care to the design of the interfaces of this module.

MODULE OF INTERNAL DIAGNOSIS

After acquisition of measurements on the equipment, this module is charged to find the internal parameters corresponding. It was implemented using an internal diagnosis method, where the minimization of the objective function is made by a genetic algorithm (Strohmeier and Buchs, 1996) implemented in a separate object module.

The architecture of the module: We have already said that the software will have to adapt to several types of refrigerating installations. This is why we have defined the concept of Fluidic Circuit Configuration (FCC). This definition includes:

- A data base gathering all the useful information used with the configuration.

- An object module containing the function of cause to effect and a procedure of recalculation of the installation.

The functions on refrigerants necessary to the calculations are taken from version 2.0 of the library provided by Solvay Fluor Und Derivate, a German builder of refrigerants.

All the object modules-implementing the genetic algorithm and each FCC) here were encoded in the form of dynamic link libraries (Dynamic Link Library: DLL) (Microsoft, 2000) thus ensuring the evolutionarity of the software.

The function of cause to effect of a FCC

Concept of state variable: For a given FCC, we will indicate by state variables the elements of any subset of independent internal parameters and their values should be sufficient to fix a complete state of the refrigerating installation.

The measurements: They consist of all the measurements that can be taken on the equipments for a given FCC. The main goal of the diagnosis is to find the best values of internal parameters leading to the measurements which were taken. From there, it arises that during an expertise, one is not obliged to take all the measurements defined for the FCC, but the more there will be measurements and the more precise will be the diagnosis. This offers a greater flexibility in the use of the program package, because installations don't have always all the desirable points of measurements.

Expression of cause to effect and fitness functions: The measurements-which are the effects-taken on site are represented by the vector $\vec{M}_S$. The causes are the state variables represented by the state vector $\vec{X}$. For a given state vector, the function of cause to effect makes it possible to calculate a corresponding measurements vector $\vec{M}_C$. We write it $\vec{M}_C = F(\vec{X})$. The fitness-which is the objective function in the genetic algorithm terminology-of the state vector [22] will thus be represented by a measure of the difference between $\vec{M}_S$ and $\vec{M}_C$, we have taken here the norm $\|\vec{M}_S - \vec{M}_C\|$, defined for a vector $\vec{V}$ of given components v_i by: $\|\vec{V}\| \sum_i |v_i|$.

The research space: The research space Γ is a rectangle in the state variable space Π, defined by

$$\Gamma = \left\{\vec{X} \in \Pi / Xi_{min} \le Xi \le Xi_{max}, \forall i\right\}$$

Before each diagnosis, default values for the parameters Xi_{min} and Xi_{max} are proposed to the user who can modified them if he wants.

THE FCC IMPLEMENTED

In this first version of the software, we have encoded only one FCC. It represents a fluidic circuit based on a mono staged cycle with mechanical vapours compression. This FCC does not model the electric part. The diagram of this cycle in a LogP-H diagram is presented in the Fig. 1.

Module of recalculation of the refrigeration installation: For a given FCC, the recalculation consists of finding the nominal values of all the parameters-internal and external-which were estimated by the module of diagnosis. The calculations are based on.

Results of the heat balance: Temperature and relative humidity wished in the room, climatic conditions and refrigerating power expected from the installations.

Parameters estimated by the internal diagnosis: Indeed, these parameters can hide correlations which would be interesting to lay out.

Standard design parameters: For example overheating in the evaporator can be fixed at 5°C. During the expertise, such default values are proposed to the user who can decide to change them.

Module of the final decision-making: This module is have been implemented as a fuzzy rule based system

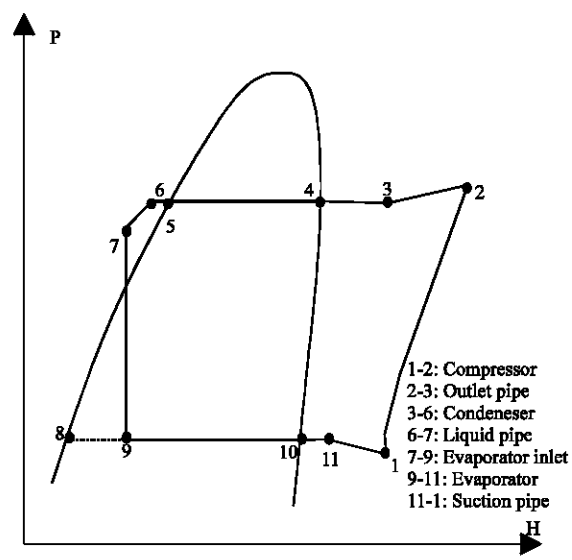

Fig. 1: Refrigerating cycle of the implemented FCC

(Tong, 1995). The decisions taken here are based on the results of diagnosis and the recalculation, in other words on the actual and the desired nominal value of each parameter-internal or externa.

The principle used: The linguistic variables here are specific to each FCC and represent all the parameters treated by the FCC. A rule has the following form:

IF Premise N°1 AND Premise N°2 AND... AND Premise N°n
THEN Conclusion.
Actions: List of actions.
Observations: List of observations on site.

Premises:
A premise is a fuzzy proposition whose general form is:

- Variable + Modifier +Adjective
- Variable is the name of a parameter treated by the FCC.
- Modifier is an optional linguistic modifier whose possible values are Very and More or less.
- Adjective represents a linguistic term and can take the values normal, low or high.

The conclusion: It is the statement of the conclusion according to the premises.

Actions: They are the corrective actions to be taken when the premises are verified.

Observations: They are the observable effects on the installations when the premises are verified. They thus make it possible to confirm physically a result of expertise.

Evaluation of the rules: The inference here consist of a simple evaluation of the rules. A catenation is indeed not necessary because of the great number of variables of decision generated by the genetic algorithm during the diagnosis. The evaluation of a rule is nothing other than the calculations of the value of truth of the conjunction of the premises of the aforementioned rule. The inference here consist of a simple evaluation of rules. A chaining is indeed not necessary because of the large numbers of decision variables generated by a genetic algorithm. The evaluation of a rule is nothing else than the calculation of the true value of the premis conjunction of the said rule.

Affiliation functions of the linguistic terms: At this step of the expertise, we have for each variable two values to spare: One obtained after diagnosis (V_D) and the other after the redimentioning (V_R). That is T% a set tolerance between 0 and 100%. Let:

- B_1 = T% x V_R, avec B1 = 0,01 si V_R=0;
- B_2 = 1,5 x T% x V_R, avec B2 = 0,015 si V_R=0;
- B_3 = 2 x T% x V_R, avec B3 = 0,02 si V_R=0.

It therefore, seemed wise for us to define the affiliation functions of the linguistic terms as Fig. 2-4.

The T% tolerance is set by the user for each of the rules, but the value in absentia is 10%. this parameter makes it possible to adjust the forms of the affiliation functions.

The linguistic modifications actually modify the affiliation function in accordance wuth the intention of the modification. The transformation of the modification used here are those introduced by Zadeh (Tong, 1995).

Evaluation: With the help of the preceding affiliation functions together with the transformations and modifications, we can evaluate each of the premises for the values of V_R and V_D given. The conjunction Min () was used for that purpose.

Therefore, if premise N°i has as affiliation value μ_i, therefore the truth value associated to this rule is $\mu = \underset{i}{\mathrm{Min}}(\mu_i)$.

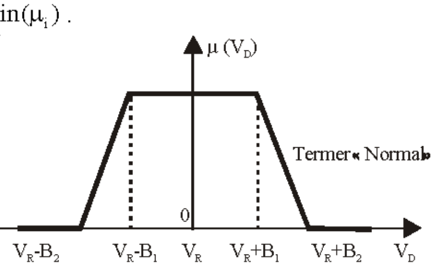

Fig. 2: Affiliation function of the « Normal » term

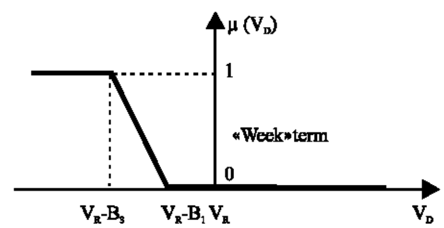

Fig. 3: Affiliation function of the « Weak » term

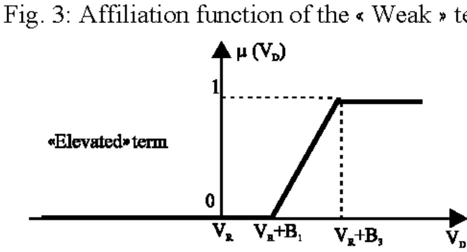

Fig. 4: Affiliation function of the «Elevated» term

Decision making: As soon as the truth value μ of the premise conjunction is known for each rule, decisions must be taken. For this purpose we have defined two thresholds:

- The S_1 threshold of « true » decision: If $\mu \geq S_1$, then we decide that the premises are true and that the conclusion of the rule is verified.
- The S_2 threshold of « false» decision: If $\mu \leq S_2$, then we decide that not all the premises are true and that the conclusion is false.

In the case where $S_2 \leq \mu \leq S_1$, then we cannot make any conclusion. we obtain what we called an undecidable conclusion. In this case, it is preferable that the user moves to the set-up to see if the corresponding observation, proposed in the statement of the rule manifested itself or not. The later will thereafter, modify the thresholds or the tolerance of the rule in question to refine future decisions.

The editor of rules: For more flexibility in the decisions, we have made provisions for an editor of rules in the application. For a given FCC, this editor will permit the user to carryout the added tasks, of modification, suppression and the edition of state rules.

Other modules: The following modules are also essential to ensure the quality of the software:

The interface: We have used a multiple documents interface with MS Windows standard (Overland, 1999). The software has been called Fronix.

The module of report editions: The program will have to edit a report at each step of the expertise or of the state of information in the data base. All these documents are generated by a text editor inserted in the software and compatible with MS Word.

The module of the data: It consist of the data base of the program and the system of project files protection of generated by the program.

- The on-line help;
- The module where is encoded the setup program.

IMPLEMENTATION AND TEST OF THE SOFTWARE

Implementation:

Hardware resources: The computer used is a PC whose principal characteristics are:

- Processor seep: 735 Mhz.
- RAM: 128 Mo.
- Hard disk: 20 Go.
- Software resources
- The operating system: MS Windows XP.
- Development tools: Our application requires a hyper convivial interface and a great computational power. To develop quickly and efficiently our interfaces, we used MS Visual Basic 6 which is very adapted for that (Kirstein, 1999; Vaiser, 1999). But all the heavy calculations were implemented as DLLs under MS Visual C++ 6; (Lippman, 1992; Frala, 1999).
- The Database Management System (DBMS): we used MS Access;
- Other resources: HTML Help for the online help and GkSetup 1.93 for the setup program.

Figure 5-7 show some interfaces of the application.

Program testing: We tested Fronix in a cold storage plant of 10000 $m^{3,}$ located at Bonaberi (aquarter in the neighbourhood of Douala-Cameroon), built in June 2002 and belonging to CONGELCAM, an enterprise in Cameroon specialised in the importation and sales of fishes.

The principal,characteristics of this plant are:

- Height: 8 m;
- Height of a door: 2,8 m;
- breadth of a door: 2,4 m;
- Insulation of the vertical walls and ceiling:sandwich board of 180 mm polyurethane rigid foam;
- Floor insulation:Concrete foundation slab of 150mm, waterproof bitumen of 15 mm polystyrene
- An expanse of a 150 mm concrete slap
- Refrigeration generator: 5 generators HK Refrigeration, the JJ27813401 model, with a semi hermetic compressor.

The trend of failure noticed: A generator of this setup present some intermittent failure not yet fully explained. The corresponding intermittent failure is as follows, stops the generator, without an abnormality being noticed on the lubrificating system. After many rearmament the generator starts back in continuity till the reappearance of the next failure some months later.

Expertise by Fronix: Here we are presenting the expertise effected with the help of Fronix on this defectives group.

Thermal balance: The constructive and running data collected were inserted into the program. The climatic profile used are those of the average condition of the month of February in the town of Douala.

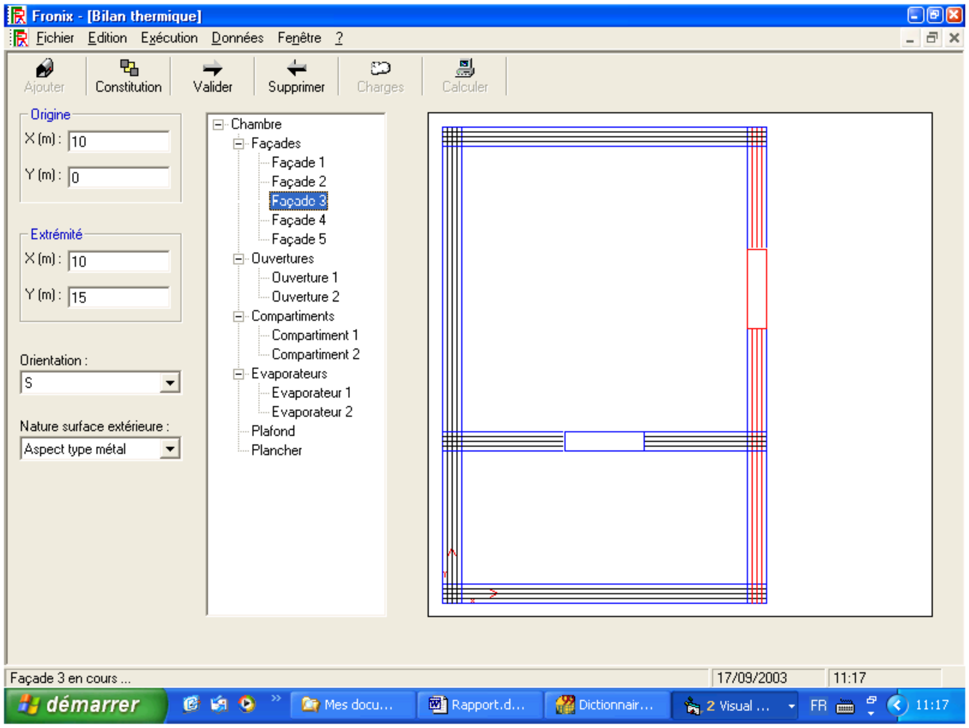

Fig. 5: The principal window for thermal balance calculation

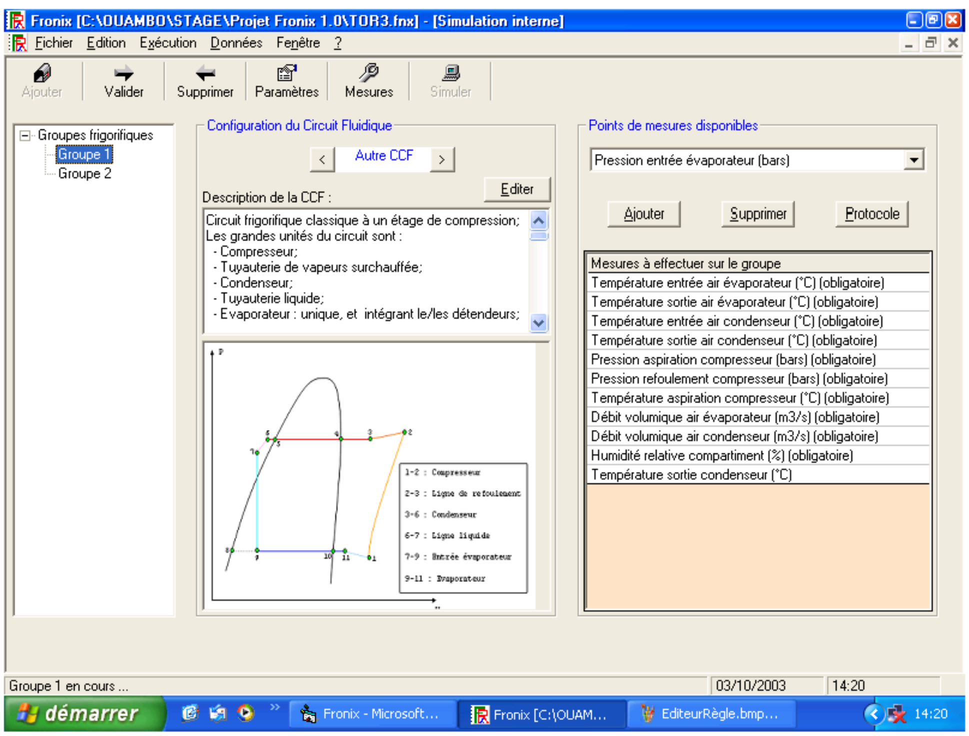

Fig. 6: The principal window for internal diagnosis

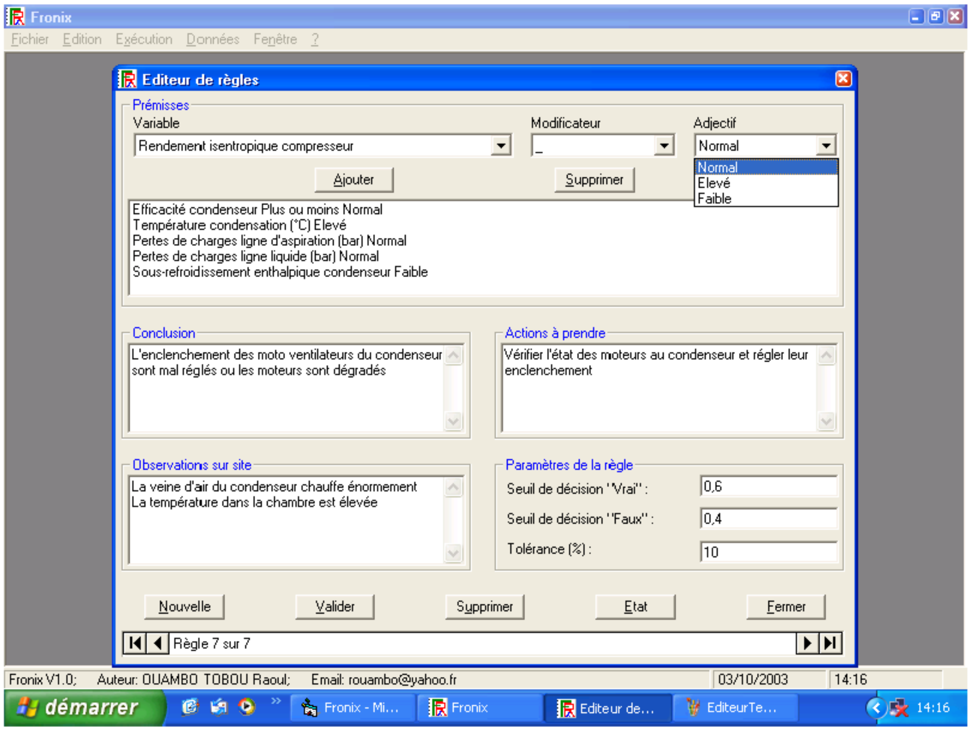

Fig. 7: The rule editor displays

Table 1: Results of the diagnostic tests carried out

		N° of trails					
		1	2	3	4	5	6
Input	Selection probability	0.9	0.9	0.9	0.9	0.9	0.95
	Mutation probability min.	0.001	0.001	0.001	0.001	0.001	0
	Mutation probability max.	0.005	0.005	0.005	0.005	0.005	0.005
	Population size	20	40	20	40	20	20
	Generation number	100	100	200	200	400	400
Output	Homogenisation parameter	10	7.5	55	27.5	35	5
	Minimum fitness	1.76	1.41	1.05	1.13	0.92	2.92
	Calculation time (minutes)	10.14	20.10	21.15	36.26	31.48	46.43

The results of the thermal balance calculation given by Fronix are:

- SAS: 38040 W;
- Principal compartment: 115248 W.

Internal diagnosis: Calculations were made with the only FCC (Fluidised Circuit Configuration) currently available. a major problem of diagnosis as we conceived it was to be able to find the parameters of the genetic algorithm leading to good results in a short space of time. To do this, we carried out trails with different parameters, by using bounds in abstainsia of state variables. The results are presented in the Table 1.

As seen from trail N°6, Very low mutation probability impedes good exploration and the results are bad. The table shows that good results can be obtained with a population of 20 individuals. This number having been set, the fitness decreases when the generation number increases, but the calculation time grows and a good compromise must be found. Here it is trial N°5 that was satisfactory.

Redimensionning: After redimensionning, the DLL of the FCC brought out the following report: «The velocity at the entrance of the suction tube is too weak ($v < 6$ m s^{-1}), there is a risk of non feedback of oil. »

Decision making: There are currently ten rules available for the FCC implemented. They all have a threshold of « true» decision of 0.6; a threshold of « false» decision of 0.4 and a tolerance of 10%. The rule that follows was activated after appraisal: « If suction temperature too low and specific volume compressor input too low then

Too much liquid in the suction piping action adjust the expansion valve the suction piping ices ».The observation stated here was well and truly confirmed on the setup.

DISCUSSION

After appraisal, it seems the failure noticed had two causes:

- A bad layout of the piping, leading to insufficient velocity to ensure a good feedback of oil;
- A bad adjustment of the expansion valve, admitting more liquid in the crankcase of the compressor, hence a greater mixing of the oil and the refrigerating fluid increasing thereby increasing the quantity of oil brought Into the compressor

It is worth pointing out to this effect that even if there is an oil separator in the circuit, the separation is not always perfect, this explains the intermittent character of the failure.

These results were obtained with a rather average FCC in terms of depth in the calculation models and yet are acceptable. After the resolution of the problem of adjusting the expansion valve, the failure was no more observed The low suction speed was therefore due to the very low specific volume at this level.

Finally, it should however be noticed that the calculation times required for diagnosis are quite high. This is due to the genetic algorithm and it is the price to pay in order to benefit from its power.

CONCLUSION

All along this research, we developed a program destined for refrigeration setup appraisals or assessments of cold rooms and adapted to many configuration. this appraisal is done in three great steps: A redimensioning, a diagnosis and decision making. The peculiarity here is that during diagnosis, in addition to the measurements taken from the set ups, the program will use a genetic algorithm in order to find out the best corresponding internal parameters(not accessible by measurements).the making of the final descision finds its self ameliorated. This decision making was implemented by a system with blur rules, in order to remain as close as possible to the human expression (imprecise and indecisive) in the statement and treatment of rules. The modularisation of the program was increased, offering in this way a geater flexibility. For this purpose, the notion of the configuration of the Fluid Circuit Configuration (FCC) was introduced, permiting the manipulation of the different types of refrigeration setups. An FCC is made of a data base and Dynamic Link Library functions(DLL: Dynamic Link Library). In this way, we shall later on add the FCC to the program without recompiling the code.

In this first version of the program, we implanted only one FCC. The application was tested on a cold storage plant of 10000 m^{-3} and the results are encouraging.

We are presently working on the development of a commercial version of the program. This research is centred on the conception of FCC which will be much more complete than that currently available.

NOMENCLATURE

API: Application Programming Interface
BASIC: Beginners All purposes Symbolic Instructions Code
COM: Component Object Model
DLL: Dynamic Link Library
FCC: Fluidic Circuit Configuration
HTML: Hyper Text Markup Language
M: Measurements vector
MDI: Multiple Document Interface
MS: MicroSoft
PC: Personal Computer
RAM: Random Access Memory
SDI: Single Document Interface
SGBD: Système de Gestion des Bases de Données
SQL: Structured Querry Language
T%: Tolerance
V: Obtained values after
X: State vector

SUBSCRIPTS

C: Calculate
D: After diagnostic
R: After Redimensioning
S: On site
i_{min}: Minimum default
i_{max}: Maximum default

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