# Use of the benchmark for PID control in engineering studies at the University of Almería [⋆]

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**Abstract:** This paper presents the methodology followed to evaluate students ability to face the challenge of controlling a refrigeration system based on vapour compression proposed as a benchmark for PID control design in the PID18 Conference. This benchmark has been also proposed as test-bed plant for the design of controllers in the subject Industrial Control Techniques at the University of Almería, Spain. The solutions proposed by the students range from simple SISO PID control loops (including anti-windup effect) to MIMO ones, including decoupling, filters and feedforward action to reject disturbances. All these solutions rely on models obtained from the reaction curve method. The selection of adequate specifications is encouraged, although students creativity has led them to exploit very aggressive specifications taking into account the different system restrictions, and obtaining very good values of the proposed evaluation indexes. © *Copyright IFAC 2018.*

Keywords: control design, PID control, control education

## 1. INTRODUCTION

Increasingly nowadays, industry requires engineers with multidisciplinary training, able to face and solve all kinds of problems. Industrial engineers (at least in Spain) have been characterized by their generalist training and, in particular, those with good background in automatic control have a base that allows them solving complex problems and meet this demand.

As stipulated in the European Higher Education Area, today students are required to acquire both knowledge and skills, but above all, it is about being able to handle these skills as a result of applying the knowledge acquired. For this reason, the resolution of problems and practical sessions take more and more importance in the curriculum of the different degrees and master's degree in engineering.

With this focus, intensive use of teaching material with a high practical content, as well as advanced simulators and interactive tools has been made at the University of Almería (UAL, South East Spain) for many years (Álvarez et al., 2013; Berenguel et al., 2016; Guzmán et al., 2012, 2013, 2016; Pasamontes et al., 2012), where the survey shown in this paper has been developed.

In the subjects of the last course (fourth course in degree level) we try to foment aspects such as problem solving in a self-taught way, as well as the competence in the pursuit of objectives. This paper presents the experience of a subject of the Degree in Industrial Electronics Engineering, where each academic year a benchmark is used to cover these objectives. In recent years, different benchmarks proposed by the Spanish Committee of Automatic Control have been used, where students from Spain and Ibero-American universities competed with each other to obtain the best evaluated solutions based on performance and control effort indexes. Examples of benchmarks have been the control of a helicopter (García-Sanz and Elso, 2006), testing of PID controllers (Alfaro et al., 2009) with 9 different plants proposed in (Aström and Hägglund, 2000), industrial boiler (Fernández et al., 2011) proposed in (Pellegrinetti and Bentsman, 1996) and adapted in (Morilla, 2012) for international competition, navigation control of a quadrotor Hernández et al. (2013), solar plants (Cabrerizo and Santos, 2017), underwater robots (Pérez et al., 2018), among others. This follows also international initiatives proposed in different conferences and at industrial level: boilers (A. S. Silveira, 2012; Ulemj et al., 2014; Meza et al., 2017), existing PID control loops (Ko and Edgar, 2004), three-tank systems (Vinagre et al., 2010), air heaters (Haugen, 2010), biological wastewater treatment plants (Sotomayor et al., 2001; Vilanova et al., 2017a,b), etc.

The objective of the benchmark in 2018 (refrigeration system based on vapour compression) is to conduct a competition among students in order to demonstrate their competencies in the development of control algorithms to meet certain specifications they propose to minimize some performance indexes. Those who obtain better results, in addition to obtaining a high grade in the subject (the benchmark is scored 20 % of the total of the subject), have the opportunity to attend the national contest of the Span-

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[⋆] This work has been partially funded by the following projects: DPI2014-55932-C2-1-R, DPI2014-56364-C2-1-R and DPI2017-84259-C2-1-R (financed by the Spanish Ministry of Economy, Industry and Competitiveness and EU-ERDF funds).

ish Committee of Automatic Control. In two occasions (2011, 2017) our students have won that contest, receiving the distinction in the annual meeting. Our experience shows that the use of benchmarks encourages teamwork, collaboration among students, “healthy” competitiveness and motivates them a lot, since they see a practical sense of all the knowledge acquired during the career.

As in the real world, the development of the benchmark has tight deadlines and aims to achieve an adequate performance of the control loops, minimizing operating costs and improving energy efficiency in the use of resources. Student autonomous work is also encouraged through the development of a report, which serves as a practice prior to the presentation of their final degree projects. The benchmark is provided at the beginning of the course and they have 3 months to develop it. They cover all aspects of modeling, identification, design and simulation of PID control loops.

Obviously, the use of a benchmark in the learning of automatic control requires the teachers responsible for the subject a high dedication, both in tutorial work during the development and resolution of it, and when correcting reports and programs delivered by students.

The paper is organized as follows: In section 2, the context in which the subject and the benchmark are placed in the career is explained. Section 3 summarizes the main features of the benchmark. In section 4, the experience performed in the academic course 2017-2018 is briefly explained, including results achieved by our students. Finally, some concluding remarks are drawn.

## 2. INDUSTRIAL CONTROL TECHNIQUES SUBJECT

The experience related in this paper has been performed at the University of Almería, where the subjects related to automatic control are taught in studies related to Industrial Engineering: Industrial Electronics Engineering, Electrical Engineering, Industrial Chemical Engineering and Mechanical Engineering. Some related subjects are also included in Computer Engineering and Agronomy degrees. The degree where automatic control has a strong implantation is Industrial Electronics Engineering, where practically half of the non-general subjects belong to the automatic control field, including: Industrial automation (2nd course), modeling and control of continuous time systems (3rd course), computer control (3rd course), industrial computing (3rd course), robotics (4th course) and industrial control techniques (4th course).

Industrial control techniques subject is thus the last one students have to pass before reaching the working market if they do not continue with master studies (where a subject related to advanced process control is also taught).

The objectives of this course are the following:

- To acquire the ability to select, design and tune different control schemes widely used in industry.
- To learn to model and simulate the behavior of dynamic systems from real data.
- To understand very basic concepts of identification, adaptive, predictive and non-linear control.

This subject focuses on industrial implementation of feedback control loops, covering the following units:

(1) Advanced PID control techniques, involving classical and modified structures, anti-windup, bumpless transfer, reference, disturbance and noise filtering and different tuning methods [4 h theory, 4 h lab sessions].
(2) Industrial control methods: feedforward, cascade, ratio, selective, split range control and control of systems with dominant delays (Smith predictor and variants) [6 h theory, 6 hours lab sessions].
(3) Multivariable control: interactions, pairing, decoupling and controller tuning [4 h theory, 4 h lab sessions].
(4) PID loop shaping: PID (and other control structures) control design based in loop shaping techniques, both in Bode (Díaz et al., 2017) and Nyquist charts (Guzmán et al., 2008) (using sensitivity and complementary sensitivity functions) [4 h theory, 4 h lab sessions].
(5) Systems identification (least-squares, including recursive and weighted approaches) and self-tuning control [4 h theory, 4 h lab sessions].
(6) Introduction to nonlinear and predictive control [2 h]. As an introduction to the master course.

The teaching guide involves information justifying the elements of interest for learning the subject, links to previous subjects, competences (basic of the profession, problem solving, ability in using ICT, ability to design control systems and knowledge about automatic control techniques).

The methodology and training activities cover the following aspects:

- In classroom hours, the teaching methodology follows master/participatory classes for each of the theory topics, exercises and demonstrations with interactive and industrial tools, audiovisual projections and realization of laboratory practices.
- With respect to the student's autonomous and group work, the student must complete: Individual study of the theoretical contents of each of the topics, assimilation of the knowledge derived from the subjects taught in the theoretical classes, resolution of the benchmark problem proposed as individual work to the student, resolution of the practical cases proposed in the laboratory practices, preparation of reports of laboratory practices and teamwork (in groups of 2 students).
- A visit to an industrial facility is done every year, where students can see how what is learned in the subject is applied in practice.

The benchmark has been used during the subject to apply the acquired knowledge, mainly using that of the first three units (where basic use of offline identification tools is anticipated to help obtaining models of the process). The students have been motivated because they knew their work was going to be used as an application example to the PID18 conference and also for the national competition. The evaluation system is based on the accomplishment of the following academically directed activities, considering all the aspects of the student's work and that are evaluated between 0 and 10 points, having to obtain more than 5 points in each one to be able to pass the subject:

- The resolution of a control benchmark problem.
- Two laboratory practices are proposed (four tank system (Johansson, 2000)).
- A final exam of the subject, consisting of a series of theoretical and practical exercises.

The final mark is obtained in the following way: Exam 60 %, benchmark 20 %, problems 15 % and participation 5 %. A minimum score of 5 points must be obtained in each of the activities. The problem solving competence (which encompasses other general competencies) as well as Skill in the use of ICT, are evaluated as Excellent, Suitable and Insufficient, having to obtain a minimum aptitude to pass this subject. The competition Skill in the use of ICT is evaluated with laboratory practices and problems.

## 3. BENCHMARK OVERVIEW

The benchmark deals with the PID control of a refrigeration system based on vapour compression. All the information is accessible through the URL [1], where also an introduction of the importance of this technology for cooling is explained. Refrigeration systems use the inverse Rankine cycle to remove heat from a cold reservoir (i.e. a cold storage room) and transfer it to a hot reservoir, normally the surroundings.

The benchmark uses a canonical one-compression-stage, one-load-demand refrigeration cycle, including an expansion valve, a compressor, an evaporator and a condenser (see Fig. 1). Refrigeration systems are closed cycles, whose components are connected through pipes and valves, involving high coupling and strong nonlinearities, the modeling of these systems being an open field. The objective of the cycle is to remove heat from the secondary flux at the evaporator and reject heat at the condenser by transferring it to the secondary flux. Following an inverse Rankine cycle, the refrigerant at low temperature and pressure enters the evaporator and evaporates removing heat from the evaporator secondary flux. Then, the compressor increases the refrigerant pressure and temperature as it enters the condenser, where first its temperature decreases, secondly it condenses and finally it may become subcooled liquid while transferring heat to the condenser secondary flux. The expansion valve closes the cycle by upholding the pressure difference between the condenser and the evaporator.

In the benchmark dynamic models of the heat exchangers are used, while expansion valves, compressor and thermal behaviour of the secondary fluxes are statically modelled. The reason is that their dynamics are usually at least one order of magnitude faster than those of the evaporator and condenser. Regarding control and the definition of performance indexes, it must be taken into account that heat transfer at the evaporator is fundamental for the overall efficiency and thus to achieve high energy efficiency while satisfying the cooling demand. As justified in the benchmark information, the approach conventionally applied in industry consists in operating the cycle with a certain degree of superheating of the refrigerant at the evaporator outlet, which is held low to approximate to the ideal behaviour. The main control objective is thus to provide the desired cooling power as efficient as possible, which implies controlling the degree of superheating. Energy efficiency is described using the Coefficient of Performance (COP), defined as the ratio between the cooling power generated at the evaporator and the mechanical power provided by the compressor. The COP depends on the characteristic enthalpies of the cycle. In the Benchmark PID 2018 a particular application of refrigeration systems is considered, where a summary of the information provided is: The cycle, working with R404a as refrigerant, is expected to provide a certain cooling power to a continuous flow entering the evaporator as secondary flux. The evaporator secondary fluid is a 60% propylene glycol aqueous solution, whereas the condenser secondary fluid is air. Neither the mass flow nor the inlet temperature of the evaporator secondary flux are intended to be controlled. Therefore, the cooling demand can be expressed as a reference on the outlet temperature of the evaporator secondary flux, where the mass flow and inlet temperature act as measurable disturbances. Regarding the condenser, the inlet temperature and mass flow of the secondary flux are also considered as disturbances. The manipulated variables are the compressor speed and the expansion valve opening. Thus, two variables (the outlet temperature of the evaporator secondary flux and the degree of superheating) are to be controlled by manipulating two variables (the compressor speed and the expansion valve opening), considering also the disturbances (inlet temperature, mass flow, inlet pressure of the condenser secondary flux and the evaporator secondary flux and compressor surroundings temperature). The COP is used as quality steady-state performance variable. Therefore, the conventional control scheme is simple: in addition to the reference imposed by the cooling demand, a low but constant set point on the degree of superheating is applied and the controller is designed to get these two variables to track their references as efficiently as possible in presence of disturbances by manipulating the compressor speed and the expansion valve opening. To design the tracking controller, the difficulty in controlling this process lies in high thermal inertia, dead times, high coupling between variables, and strong nonlinearities. Different control approaches are summarized in the benchmark documentation, which includes a description of the refrigeration system and its control,

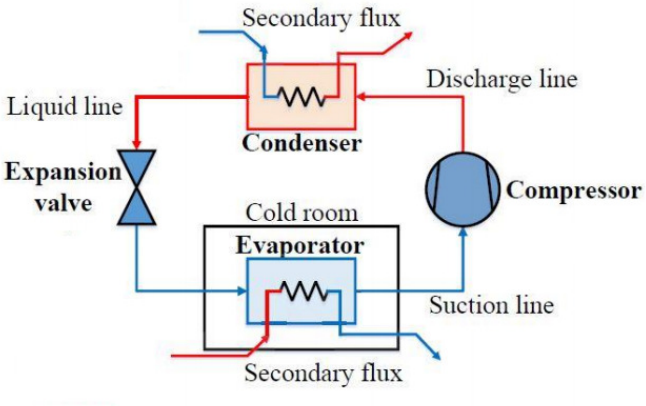

Fig. 1. General diagram of the refrigeration system

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[1] http://servidor.dia.uned.es/ fmorilla/benchmarkPID2018/

some details about the dynamic modelling of vapour compression refrigeration systems and instructions on how to test and compare the performance of multivariable PID controllers. Full documentation about the Benchmark PID 2018 can be found in the website, including an appendix entitled The MATLAB & Simulink files to approach the Refrigeration System Control Problem.

## 4. BENCHMARK EXPERIENCE WITH STUDENTS

This section summarizes the experience of using the benchmark and the results obtained by the students in the academic course 2017-2018. The benchmark is introduced and provided to the students in the first unit. The motivation relies on giving them a real (simulated) process in which they can apply all the previous knowledge on control engineering they have acquired different subjects, including what they are going to learn throughout the Industrial Control Techniques subject. They slowly become familiar with the process while implementing the new concepts from the theoretical and laboratory lessons. Notice that the whole work is done by the students and the lecturer only helps them answering the doubts raised and giving suggestions. The course started in September 18, and the deadline to present the benchmark results was December 20. The steps that they usually follow along the course are the following:

- First, students obtain the models from the plant by applying the ideas learned at the third course of the degree in the Modelling and Control of Continuous System subject. They make step changes on the main input variables and disturbances, and observe the resulting effects. Then the reaction curve method is used to calculate the linear models around the given operating point.
- Once the models are calculated, all of them are validated. In this step, many students learn to use the Matlab Systems Identification Toolboox by themselves (with brief explanations from the teachers), that later is explained in the second part of the subject.
- Then, the resulting models are used to determine the paring of the variables in the MIMO system by using the Relative Gain Array (RGA) method by Bristol.
- Afterwards, PID controllers are designed for the the different control loops. At this stage, the students analyze and select the best tuning method for the PID controllers.
- When all the basic PID control loops are implemented and tuned, they start to introduce new control techniques learned in the subject to face the different control problems. So, they study, design and implement feedforward compensators to reduce the measurable disturbances action, antiwindup to cope with saturation of the integral part of the controller, decoupling structures to reduce the interaction between the plant variables, cascade control, ratio control, and any other control approaches learned through the course. The main objective is to minimize a cost function (which is described below) as much as they can, but justifying all the changes and modifications done on the controller parameters to fulfill that objective.
- Once the whole control scheme is implemented and tested, the students must write a document summarizing and motivating the different steps they have performed to reach the final solution. This document follows a six-page paper structure to show them how a conference manuscript should be prepared.

Notice that, at the same time, they are learning new control concepts and improving some important skills for their future as engineers. For instance, from a technical point of view, they face problems such as measurement noise filtering, initialization of the linear compensators to properly work around the operating points, inversion problems, time delays, etc. On the other hand, they learn how to prepare a technical report, which is very important from academic and industrial points of view. During all the course, students frequently attend tutorial lessons to discuss the advances with the different lectures of the subject. The experience of these discussions have been very productive and gratifying.

Such as commented above, the benchmark objective consists in minimizing a cost function. This cost function evaluates the results of the proposed control structure with respect to a base control approach proposed by the benchmark developers. This cost function evaluates the transient response, the violation of the minimum overheating restriction and energetic efficiency on the steady state. The final mark for the benchmark problem is calculated considering the cost function value and the quality of the report.

| Group | J | DM | BM | DF | FF | RF |
|---|---|---|---|---|---|---|
| 15 | 0,1776 | 9 | 9,5 | X | X | |
| 18 | 0,1945 | 9,1 | 9,29 | X | X | X |
| 7 | 0,2699 | 7,2 | 8,08 | | X | |
| 11 | 0,2717 | 9 | 8,88 | X | X | |
| 1 | 0,3557 | 5,2 | 6,67 | X | | |
| 19 | 0,3765 | 7 | 7,46 | | | |
| 4 | 0,3771 | 8 | 7,75 | X | | |
| 8 | 0,3883 | 6 | 6,54 | X | X | |
| 14 | 0,4624 | 6,3 | 6,33 | X | X | |
| 13 | 0,4760 | 7 | 6,63 | X | X | |
| 20 | 0,4782 | 6 | 5,92 | | | |
| 5 | 0,4218 | 6,3 | 5,71 | X | | |
| 16 | 0,5802 | 6 | 5,50 | X | X | |
| 10 | 0,6725 | 6 | 5,29 | | | |
| 2 | 0,9249 | 7,5 | 5,58 | | | |
| 12 | 1,5166 | 7 | 5,38 | X | X | |

Table 1. Benchmark group results. The acronyms represent: J (benchmark cost function value) DM (Documentation Mark), BM (Benchmark Mark), DF (Decoupling Filter), FF (Feedforward), RF (Reference Filter).

In the 2017/2018 academic course, 20 groups of students were involved in the subject and only 16 of them presented the benchmark results. So, all the provided solutions were evaluated and analyzed. Table 1 summarizes the results for the different groups. As observed, four groups were able to reduce cost function value below $0,4$, which is a very nice result according to the indications given by the benchmark developers. The three first groups (15, 18 and 7) were the ones selected to participate in national contest of the Spanish Committee of Automatic Control (they have to present their solutions in May 2018).

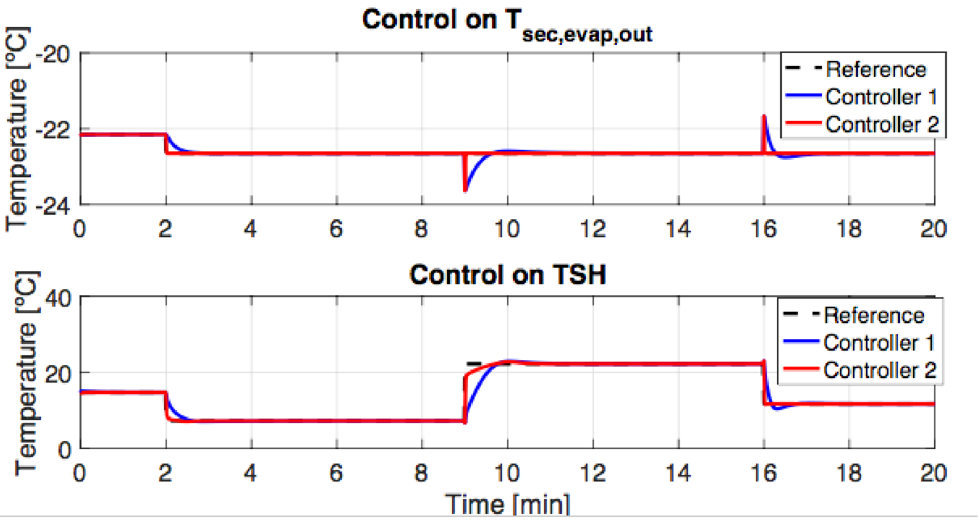


Fig. 2. Process outputs. Controller 1 and Controller 2 represent the reference solutions given by the benchmark developers and the students (group 15) respectively.

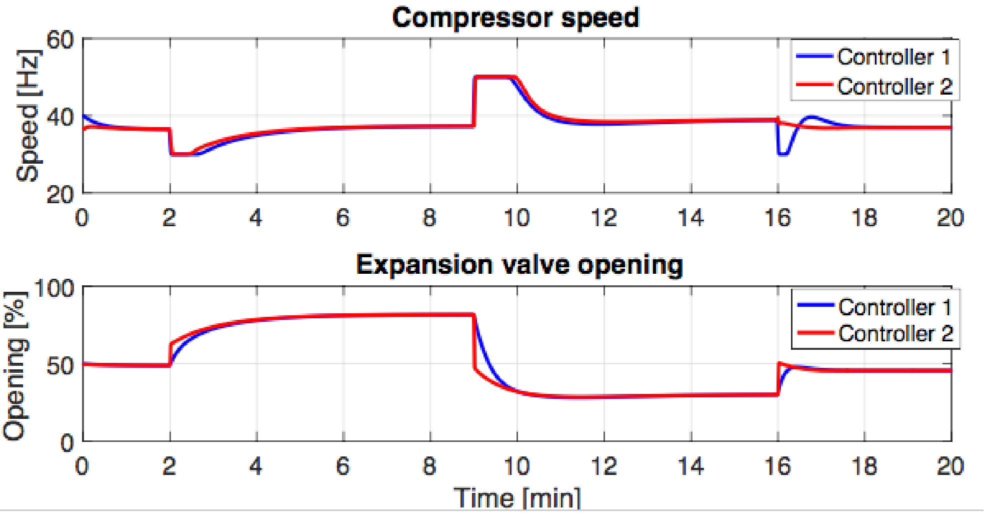
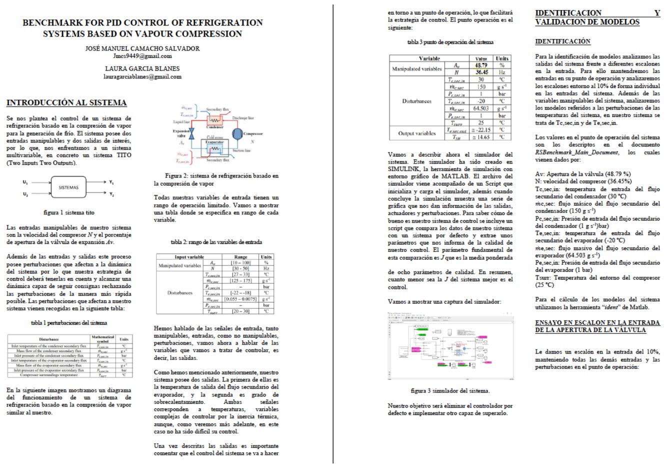


Fig. 3. Control signals. Controller 1 and Controller 2 represent the reference solutions given by the benchmark developers and the students (group 15) respectively.

From the table it can be seen how groups were evaluating different control structures, where some of them used decouplers, feedforward compensators and reference filters, and other just only PID controllers. The pole-zero cancellation method was used by all the groups to tune the PID controllers, except group 2 that used $\lambda$ and SIMC methods. On the other hand all the groups included the antiwindup scheme in the PID controllers.

The group 15 was the best one obtaining a cost function value of 0.1776. This group used decouplers for both control loops and feedforward compensators for the measurable disturbances. The PID controllers were tuned with a very aggressive closed-loop specifications and allowing an almost perfect solution. Figures 2 and 3 show the control results. It can be observed that the control approach proposed by the students considerably improve the results given by the benchmark developers. The reference signals are followed perfectly and very fast, and the coupling and disturbance effects are practically removed. Finally, Figure 4 shows an example of the reports presented by the students following a two-column paper format. In this case, the best report presented by the group 18 is shown.



BENCHMARK FOR PID CONTROL OF REFRIGERATION SYSTEMS BASED ON VAPOUR COMPRESSION

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INTRODUCCIÓN AL SISTEMA

Se nos plantea el control de un sistema de refrigeración basado en la compresión de vapor para la generación de frío. El sistema posee dos entradas manipulables y dos salidas de interés, por lo que, nos enfrentamos a un sistema multivariable, en concreto un sistema TITO (Two Inputs Two Outputs).

figura 1 sistema tito

Las entradas manipulables de nuestro sistema son la velocidad del compresor $N$ y el porcentaje de apertura de la válvula de expansión $Av$.

Además de las entradas y salidas este proceso posee perturbaciones que afectan a la dinámica del sistema por lo que nuestra estrategia de control deberá tenerlas en cuenta y alcanzar una dinámica capaz de seguir consignas rechazando las perturbaciones de la manera más rápida posible. Las perturbaciones que afectan a nuestro sistema vienen recogidas en la siguiente tabla:

tabla 1 perturbaciones del sistema

| Disturbance | Mathematical symbol | Units |
|---|---|---|
| Inlet temperature of the condenser secondary flux | $T_{c,sec,in}$ | °C |
| Mass flow of the condenser secondary flux | $\dot{m}_{c,sec}$ | g s$^{-1}$ |
| Inlet pressure of the condenser secondary flux | $P_{c,sec,in}$ | bar |
| Inlet temperature of the evaporator secondary flux | $T_{e,sec,in}$ | °C |
| Mass flow of the evaporator secondary flux | $\dot{m}_{e,sec}$ | g s$^{-1}$ |
| Inlet pressure of the evaporator secondary flux | $P_{e,sec,in}$ | bar |
| Compressor surroundings temperature | $T_{surr}$ | °C |

En la siguiente imagen mostramos un diagrama del funcionamiento de un sistema de refrigeración basado en la compresión de vapor similar al nuestro.

Figura 2: sistema de refrigeración basado en la compresión de vapor

Todas nuestras variables de entrada tienen un rango de operación limitado. Vamos a mostrar una tabla donde se especifica en rango de cada variable.

tabla 2: rango de las variables de entrada

| Input variable | | Range | Units |
|---|---|---|---|
| Manipulated variables | $A_v$ | [10 – 100] | % |
| | $N$ | [30 - 50] | Hz |
| Disturbances | $T_{c,sec,in}$ | [27 – 33] | °C |
| | $\dot{m}_{c,sec}$ | [125 – 175] | g s$^{-1}$ |
| | $P_{c,sec,in}$ | – | bar |
| | $T_{e,sec,in}$ | [-22 – -18] | °C |
| | $\dot{m}_{e,sec}$ | [0.055 – 0.0075] | g s$^{-1}$ |
| | $P_{e,sec,in}$ | – | bar |
| | $T_{surr}$ | [20 – 30] | °C |

Hemos hablado de las señales de entrada, tanto manipulables, entradas, como no manipulables, perturbaciones, vamos ahora a hablar de las variables que vamos a tratar de controlar, es decir, las salidas.

Como hemos mencionado anteriormente, nuestro sistema posee dos salidas. La primera de ellas es la temperatura de salida del flujo secundario del evaporador, y la segunda es grado de sobrecalentamiento. Ambas señales corresponden a temperaturas, variables complejas de controlar por la inercia térmica, aunque, como veremos más adelante, en este caso no ha sido difícil su control.

Una vez descritas las salidas es importante comentar que el control del sistema se va a hacer en torno a un punto de operación, lo que facilitará la estrategia de control. El punto operación es el siguiente:

tabla 3 punto de operación del sistema

| Variable | | Value | Units |
|---|---|---|---|
| Manipulated variables | $A_v$ | 48.79 | % |
| | $N$ | 36.45 | Hz |
| Disturbances | $T_{c,sec,in}$ | 30 | °C |
| | $\dot{m}_{c,sec}$ | 150 | g s$^{-1}$ |
| | $P_{c,sec,in}$ | 1 | bar |
| | $T_{e,sec,in}$ | -20 | °C |
| | $\dot{m}_{e,sec}$ | 64.503 | g s$^{-1}$ |
| | $P_{e,sec,in}$ | 1 | bar |
| | $T_{surr}$ | 25 | °C |
| Output variables | $T_{e,sec,out}$ | ≅ -22.15 | °C |
| | $T_{SH}$ | ≅ 14.65 | °C |

Vamos a describir ahora el simulador del sistema. Este simulador ha sido creado en SIMULINK, la herramienta de simulación con entorno gráfico de MATLAB. El archivo del simulador viene acompañado de un Script que inicializa y carga el simulador, además cuando concluye la simulación muestra una serie de gráfica que nos dan información de las salidas, actuadores y perturbaciones. Para saber cómo de bueno es nuestro sistema de control se incluye un script que compara los datos de nuestro sistema con un sistema por defecto y extrae unos parámetros que nos informa de la calidad de nuestro control. El parámetro fundamental de esta comparación es $J$ que es la media ponderada de ocho parámetros de calidad. En resumen, cuanto menor sea la $J$ del sistema mejor es el control.

Vamos a mostrar una captura del simulador:

figura 3 simulador del sistema.

Nuestro objetivo será eliminar el controlador por defecto e implementar otro capaz de superarlo.

IDENTIFICACION Y VALIDACION DE MODELOS

IDENTIFICACIÓN

Para la identificación de modelos analizamos las salidas del sistema frente a diferentes escalones en la entrada. Para ello mantendremos las entradas en su punto de operación y analizaremos los escalones entorno al 10% de forma individual en las entradas del sistema. Además de las variables manipulables del sistema, analizaremos los modelos referidos a las perturbaciones de las temperaturas del sistema, en nuestro sistema se trata de Tc,sec,in y de Te,sec,in.

Los valores en el punto de operación del sistema son los descriptos en el documento *RSBenchmark_Main_Document*, los cuales vienen dados por:

Av: Apertura de la válvula (48.79 %)
N: velocidad del compresor (36.45%)
Tc,sec,in: temperatura de entrada del flujo secundario del condensador (30 °C)
ṁc,sec: flujo másico del flujo secundario del condensador (150 g s$^{-1}$)
Pc,sec,in: Presión de entrada del flujo secundario del condensador (1 g s$^{-1}$)bar)
Te,sec,in: temperatura de entrada del flujo secundario del evaporador (-20 °C)
ṁe,sec: flujo masivo del flujo secundario del evaporador (64.503 g s$^{-1}$)
Pe,sec,in: Presión de entrada del flujo secundario del evaporador (1 bar)
Tsurr: Temperatura del entorno del compresor (25 °C)

Para el cálculo de los modelos del sistema utilizamos la herramienta "*ident*" de Matlab.

ENSAYO EN ESCALON EN LA ENTRADA DE LA APERTURA DE LA VÁLVULA

Le damos un escalón en la entrada del 10%, manteniendo todas las demás entradas y las perturbaciones en el punto de operación:

Fig. 4. Report example developed by group 18.

## 5. CONCLUSIONS

This paper has shown the experience of using the PID18 control benchmark in a subject related to Industrial Control Techniques at the University of Almería. From our point of view, this kind of benchmark systems are quite useful for motivating students and helping them applying the acquired knowledge. The conclusions drawn from the actual benchmark are quite similar to those obtained with previous ones. Although the deadline has been hard to reach, the comments from the students survey have been quite positive.

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