DEVELOPMENT OF A TEST BENCH FOR A LABORATORY STIRLING MACHINE THROUGH FINAL DEGREE PROJECT

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Abstract

Generally, students in engineering education tend to carry out their Final Degree Project tutored in one discipline, but collaboration between different areas of knowledge or disciplines in the tutoring of Final Degree Projects enriches the training of students. This paper presents the experience of cooperation between the areas of knowledge of Thermal Machines and Electronics through the combined tutoring of Final Degree Project, aimed at obtaining the degrees of Electronic, Robotics and Mechatronics Engineering and Mechanical Engineering at the University of Malaga. All the projects have been focused on the development and manufacture of a test bench for a laboratory Stirling machine that can work either as a thermal engine, producing mechanical power, or as a refrigeration machine, if it is mechanically driven by an electric motor. With this co-tutoring, the students have had the possibility to develop skills both in the field of electronics and thermal machines. The tutoring of all the Final Degree Projects has been carried out simultaneously, encouraging collaborative work among the students.

In addition to the tutoring of the Final Degree Projects, common scripts have been prepared for practical laboratory lessons in the Electronics and Thermal Machines subjects.

Keywords: Engineering education; Stirling machine; Field Programmable Gate Array (FPGA); Virtual electronic instrumentation, Practical lessons.

1 INTRODUCTION

The FDP (Final Degree Project) is a compulsory subject in the studies of official Bachelor's degrees. It must be geared towards acquiring the general competences defined in the degree and, where appropriate, those other competences included in the descriptive sheet of the degree's Verification Report, [1], [2].

The FDP consists of an autonomous and individual work that each student carries out under the guidance of a tutor, who will act as a dynamiser and facilitator of the learning process.

A FDP could be defined as the realization of a project that integrates and develops the contents received, capacities, competences and skills acquired during the teaching period of the degree.

On the other hand, a large part of the electronics and mechanical engineering subjects in the final years of the degrees taught at the School of Industrial Engineering of the University of Malaga, have a high practical content that is carried out in the laboratories. However, despite the high number of practical lessons, students complain about the absence of connection between these practical lessons and the systems they will work with in their professional future. This has led to cooperation between knowledge areas through the tutoring of joint FDP on a real platform and making use of tools that the students use in the practical lessons and which are the same tools that many of them will use in their future working environment.

All the work carried out and proposed is focused on the adaptation of a laboratory Stirling machine test bench in its different aspects: mechanical, energetic and electronic.

It should be noted that it is a Stirling machine and not a Stirling engine because the laboratory model available is reversible. In other words, when heat is applied to this Stirling machine, it behaves like an engine, producing mechanical power. One of the current applications of this type of engine under research is the solar engine, where the heat applied to the engine comes from solar concentrators, and therefore it would have an engine whose energy source would be completely renewable. However, when mechanical power is applied to the Stirling machine, it behaves like a cooling machine, producing two thermally differentiated zones with respect to the temperature of the environment, a cold zone (lower

ISBN: 978-84-09-37758-9

temperature than the ambient temperature) and another hot zone (higher temperature than the ambient temperature).

Therefore, the main objective is to develop and implement a mechanical and electronic system for the monitoring and control of a laboratory Stirling machine test bench. For this purpose, the latest trends in programmable logic systems using FPGA will be used.

The Final Degree Projects focus on the following points:

1 Design and implementation of a test bench for the Stirling machine.

2 Improve the acquisition of Stirling machine parameters, implementing new sensors and improving the existing ones.

3 Improve signal conditioning electronics.

The students involved in the FDP will be able to benefit from working on a real platform, where they will apply knowledge from different disciplines, being advised by researchers from different areas of knowledge.

In addition, it is possible to share didactic resources in subjects taught by the Department of Mechanical, Thermal and Fluids Engineering and the Department of Electronics. Not only will the same platform be used, but it will also give rise to the sharing of ideas and points of view in the courses taught. There will also be multidisciplinary practical sessions where students will be able to learn different concepts on the same platform.

2 METHODOLOGY

2.1 Initial state of the Stirling machine

The Stirling machine used in this work is shown in Fig. 1. It is of the gamma type. It consists of a horizontal cylinder called displacer and a vertical cylinder known as the power cylinder. Attached to the flywheel is a dynamo/electric motor. It can operate in two different ways:

1 As a Stirling engine: Heat is applied to the right side of the displacer (Fig. 1) by means of a flame and the power piston drives the flywheel, which in turn moves the dynamo, producing electricity.

2 As a cooling machine: The dynamo is converted into an electric motor and drives the flywheel, which in turn moves the power piston. Due to the motion of the Stirling machine a thermal difference is produced between the tips of the displacer. The tip on the left becomes a cold zone (lower temperature than the ambient temperature) and the tip on the right of the displacer becomes a hot zone (higher temperature than the ambient temperature). The right-left position of the zones on the displacer depends on the direction of rotation of the flywheel. Changing the direction of rotation changes the position of the thermal zones. The hot zone moves to the left side of the displacer and the cold zone moves to the right side.

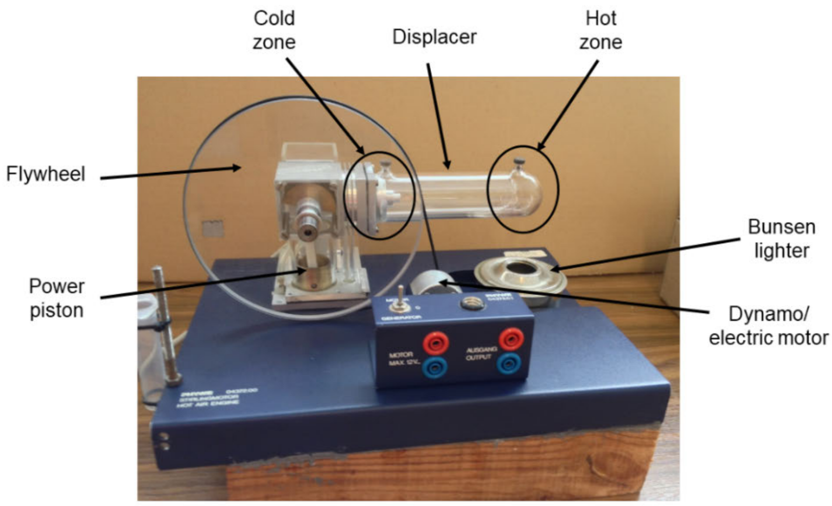

Figure 1. Initial state of the laboratory Stirling Machine.

2.2 Approach

The methodology used for each FDP is somewhat complicated by the fact that they are all highly interrelated (sequential or ordered in time).

The standard procedure proposed by the current School of Industrial Engineering [2] is followed for the preparation of a FDP, which, in summary, can be divided into the following phases ordered in time:

1. Problem statement: the context of study, state of knowledge and background, if any, a possible design and elaboration of time diagrams of the work is established. This approach takes the form of a preliminary project that will be evaluated by a committee representing all the areas of knowledge taught at the School. This committee applies the pre-established quality criteria and validates the viability of the project.
2. Design and implementation of the proposed solution: This phase is the one that extends over the longest period of time. It is where all the experimental and/or modelling part of the FDP is carried out.
3. Preparation of the dissertation results report: In it, the student will produce the document that reflects all their work and must defend it before an examining board.
4. Defence of the FDP This will be the final phase of assessment in which the student will present and respond to the questions posed by the examining board.

Each FDP must follow this procedure, which is estimated to last 6 months. It should be noted that, since all the work is related, they must be ordered in time, unless they can be carried out simultaneously. An attempt has been made to parallelise all the FDP in the most optimal way, always taking into account the resources and teaching staff available.

3 RESULTS

3.1 Tutored Final Degree Projects

The tutored Final Degree Projects are as follows:

1. Design and assembly of an experimental installation for a laboratory Stirling engine, [3]: In this work, a versatile test bench was created to experimentally test the Stirling machine. Fig. 2 shows the platform that has been designed to experimentally test the Stirling engine. This FDP was tutored in the Department of Mechanical, Thermal and Fluids Engineering.

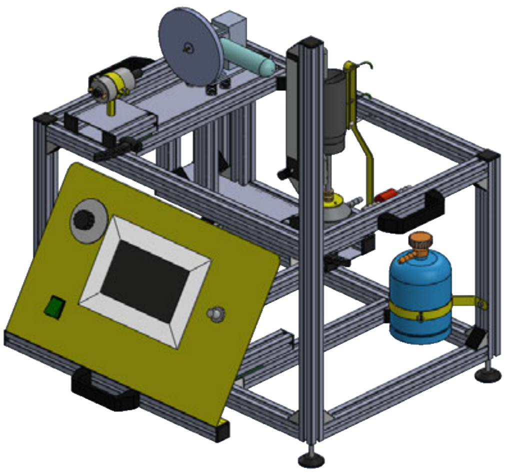

Figure 2. Design of the platform for the experimental tests.

2. Monitoring of thermodynamic parameters of a Stirling machine, [4]: In this work, a data acquisition board based on APSoC (All Programmable System-on-Chip) ZYBO (ZYnq Board) [5] has been implemented to monitor the sensors attached to the Stirling machine (pressure inside the power cylinder, temperatures, volume of the power piston chamber and speed). In addition, the results are displayed on a Nextion NX4024T032 TFT (Thin-Film Transistor) touch screen. Fig. 3 shows the connection between the different electronic equipment. This FDP was tutored in the Department of Electronic.

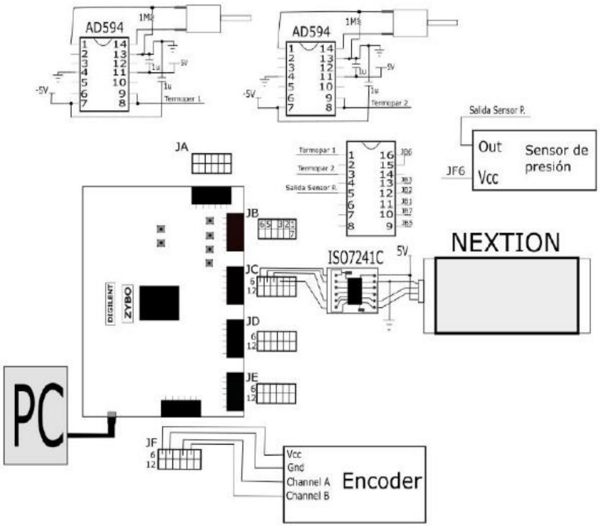

Figure 3. Connection of the final electronic circuit.

3 Stirling machine simulator in LabVIEW®, [6]: A program has been developed in LabVIEW® software, [7], which simulates the behaviour of the Stirling machine. The input data window available to the user is shown in Fig. 4. This FDP was tutored in the Department of Electronic.

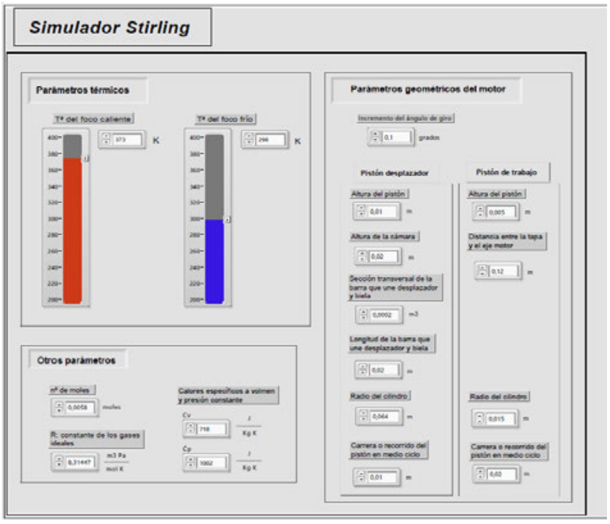

Figure 4. Machine data entry interface.

4 CFD (Computational Fluid Dynamics) modelling of a laboratory Stirling machine, [8]: This consists of a three-dimensional model of the laboratory Stirling machine. This model faithfully reproduces the Stirling machine, so that, on the one hand, it is a starting point for the design of experimental tests and, on the other hand, it serves to obtain results that cannot be measured experimentally. Fig. 5 shows the 3D model of the Stirling machine with the meshing used. The horizontal cylinder is the displacer and the vertical cylinder is the power cylinder. This FDP was tutored in the Department of Mechanical, Thermal and Fluids Engineering.

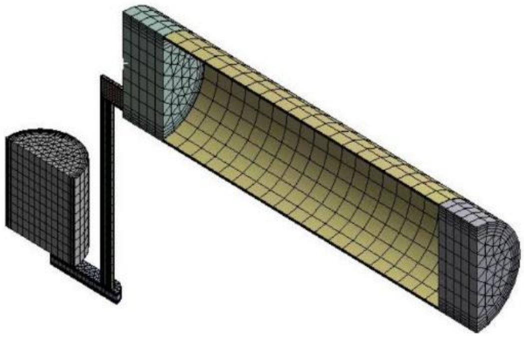

Figure 5. 3D model of the Stirling machine.

5 Modelling of the laboratory Stirling machine, [9]: In this work, the analytical Schmidt model [10] has been implemented. This model reproduces in an approximate way the behaviour of the laboratory Stirling model. This FDP was tutored in the Department of Mechanical, Thermal and Fluids Engineering.

3.2 Finished test bench of the Stirling machine

Fig. 6 shows the finished test bench of the Stirling machine. Fig. 6. left shows the position of the Nextion screen, the Stirling machine and the Bunsen lighter which is used to make the machine work as a Stirling engine. Fig 6. right shows a zoom of the Stirling machine, the sliding platform for coupling the electric motor to the Stirling machine and thus converting it into a refrigeration machine.

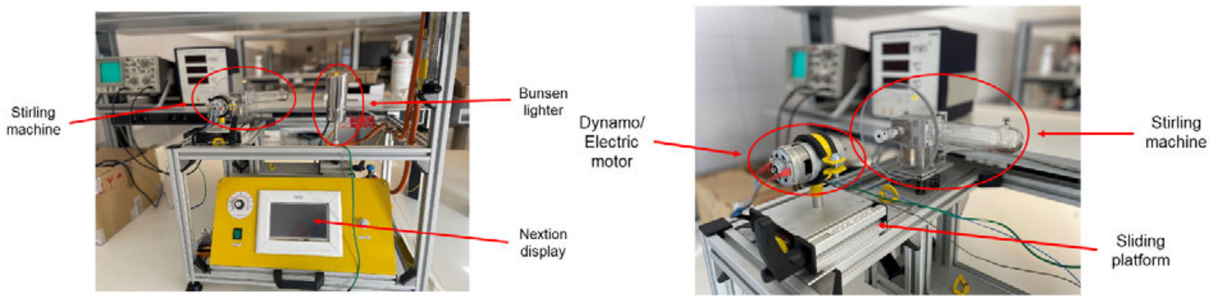

Figure 6. Test bench in its final state.

3.3 Practical lessons for subjects

The titles and brief summaries of the practical sessions are as follows:

1 Monitoring the thermodynamic parameters of the laboratory Stirling machine: The aim of this practical laboratory lesson is to apply the knowledge learnt in class about the thermodynamics of combustion engines and to compare what has been learnt with the results obtained from a Stirling machine. The student will be able to study the pressure-volume diagram of the machine, monitor the evolution of all the parameters of the machine with respect to time and monitor the value of all the parameters of the machine in real time or by means of the slow reproduction of a sample. Aimed at practical lessons in thermodynamics or thermal engines subjects.

2 Creation of a communication protocol between an APSoC, a Nextion display and the Stirling machine: The aim of this practical is to learn how to program an APSoC to read the thermodynamic parameters of the Stirling machine and the connection and interaction with the Nextion display. Aimed at practical lessons in Electronics subjects.

3 Introduction to LabVIEW® through the use and analysis of the Stirling Simulator: The main objective of this practical lesson is to get to know the LabVIEW® tool from a practical point of view. The student will learn how this software works, what applications it offers and how to work with it. Aimed at practical lessons in Electronics subjects.

4 Analysis of the Stirling machine through its simulator in LabVIEW®: The main objective of this practical lesson is to use the Stirling Simulator to test the knowledge learned about the thermodynamics of external combustion engines presented in class without the need of the real

engine. The student will be able to see the pressure-volume diagram generated by the simulated engine, as well as its thermodynamic parameters. They will be able to vary the different input parameters to see what results are generated depending on these. Aimed at practical lessons in thermodynamics and thermal engines subjects.

4 CONCLUSIONS

As a result of this experience, five FDP have been carried out, three of which led to the award of the degree in Mechanical Engineering and two of them to the degree in Electronic Engineering, Robotics and Mechatronics. During the process, the students were supported by lecturers from different areas, which allowed them to reinforce and integrate the knowledge acquired during their training.

During this experience there have been a series of difficulties that have had to be faced and which have delayed the development of the experience. Among them, the following should be highlighted:

1) Difficulty in finding students who would like to do this type of FDP. Although the idea of implementing a real system is attractive, it has been observed that this type of FDP conveys an idea of difficulty that leads to rejection on the part of students.

2) Difficulty in meeting the deadlines initially proposed for each FDP. Given that this task has to be made compatible with other subjects, the amount of time devoted to it is not the time initially considered. This has complicated the sequencing of the FDP.

Despite the difficulties encountered, the students expressed great satisfaction with the completion of their FDP. What they valued most was the fact that they were able to build a real system, with the knowledge acquired from different disciplines. They were proud and surprised by the result.

In addition, four practical laboratory lessons have been prepared. Two of them are for thermodynamics and thermal machines subjects and the other two for electronics subjects.

ACKNOWLEDGEMENTS

The authors would like to thank the University of Malaga for its support through the educational innovation project PIE19-080.

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