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INDUSTRIAL UNDERGRADUATE PROJECT - REMOTE MONITORING FOR SCREW COMPRESSORS

Kailash LUCKKANA, Varun PATEL, Vaibhav NEGI, Harshay RAIPANCHOLI, Ivan YOLA, Ashvin DHUNPUT and Ahmed KOVACEVIC
School of Engineering and Mathematical Sciences, City University London

ABSTRACT
European Global Product Realisation (EGPR) is an undergraduate group design project for the final year engineering students at City University, London. It involves collaborating with students from five different European Universities on a commercial design project for an industrial partner. The aim of the project is to equip students with the necessary skills to solve real multidisciplinary design problems, using a systematic and structured engineering design process.
In order to acquaint the students with the engineering design process, a preparatory project was set up between a UK based manufacturer of screw compressors and the students at City University, London, prior to the main EGPR project. The task was to develop a concept for a remote monitoring system to be integrated into a screw compressor produced by Howden Compressors Ltd, with the aim of gathering operational parameters including power and mass flow rate.
During the project, the students were required to use their existing engineering experience in order to find a niche area for their contribution in the design of this complex multidisciplinary system. This required close collaboration with the industrial partner to develop a common vision and approach. The students gradually realised that the concepts of physical sensing and performance calculating functions were the areas where the industrial partner was struggling and it was mutually agreed for students to concentrate on this area. This paper describes achieved concepts including brief overview of techniques used in the process. It also outlines benefits that the University, industrial partner and students found through this collaboration.

Keywords: European global project realisation, engineering design process, students experience

1 INTRODUCTION
European Global Product Realisation (EGPR) is undergraduate group design project for the final year engineering students at City University, London. It involves collaborating with students from five different European Universities on a commercial design project for an industrial partner. The aim of the project is to equip students with the necessary skills to solve real multidisciplinary design problems, using a systematic and structured engineering design process. Details about this project are given in [1], [2] and [6].
The student team which was expected to participate in this international course consisted of four aeronautical MEng students and one mechanical BEng student. Although in the engineering syllabus at City University, engineering design is thought in several courses starting from year 1, the students did not have experience of the process in real life situations. More on competences required for this course is given in [2] and [7].
Therefore it was necessary to set up a real life industrial project for this group of students prior to the main EGPR project in order to prepare them for the challenges of the full international course. The preparatory project was set up at the beginning of the academic year in October with the leading manufacturer of screw compressors Howden Compressors Ltd from Scotland.
Screw compressors are today the most common type of positive displacement compressors with applications stretching across air compression, refrigeration, oil, gas and petrochemical industries world-wide. Due to their compactness, efficiency and reliability, the operating range of these machines is continually being increased. Since City University has one of the leading centres in design of screw compressors a project was agreed between Howden and the students to provide the students with a real life problem requiring the use of the engineering design process to develop a solution.

The aim of the project was to develop concepts for a monitoring system which would enable remote collection of compressor operational data. The latter would include inlet and outlet temperatures and pressures, rotational speed, mass flow rate/capacity and power. For the company, collected data would be used in the development of proprietary selection software. The operational data could also be used to evaluate effects of upgrades of the screw compressor features. Remote monitoring is the only option for the company to get accurate performance data of their machines in the field as their production testing is always performed on air while in reality compressors work with anything but air. Further development of such monitoring system may lead to embedded control applications. Challenges of this project are technical, economical and legal. Technically, monitoring is required in remote places with small opportunity for maintenance; the machine may handle gases with changing characteristics that may be flammable and explosive; monitoring should not effect performance or operation by any means. Legally, many users of the compressor systems are not likely to disclose the performance of the machine. Economically, the monitoring system should be just a small fraction of the cost of the overall system.

The challenge was that students did not have any knowledge on screw compressors nor experience on collaborating with industry. The project was carried out by following a structured engineering design process in just two phases; problem understanding (research) and conceptual design, Figure 1. [7]. It lasted 10 weeks and consisted of two main design reviews.

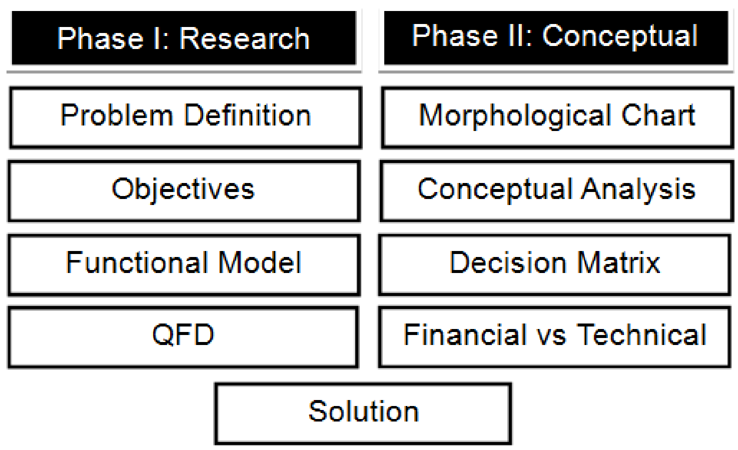

Figure 1. Breakdown of tools used in the applied design process

This paper addresses work performed in these two phases of the engineering design process and how effective the self-learning of the practical aspects of the design process was for a team not fully versed in the process and inexperienced in dealing with industry.

2 RESEARCH PHASE

The first task in the research phase was to investigate relevant competitors and any similar products that are currently in use on the market. Students found a number of compressor companies that currently benefit from monitoring systems in many different ways. Some monitor only few important parameters for reliability issues; for example, just the mass flow rate in which case large fluctuations will raise alarm and the flow rate will be adjusted automatically through the inlet valve. A group of competitors monitor only pressure levels at various points in the screw compressor for safety reasons. Others, instead of monitoring the compressor block will use monitoring of the compressor system to operate and ensure reliability of the compressor. However in majority of cases they will not install sensors to comprehensively measure all parameters for performance validation which was one of the requirements required of this project.

The remote monitoring system which was to be developed in this project should offer several advantages over the systems currently available on the market. In addition to constantly check the performance of the compressor block, it should include means to provide long term reliability of the compressor and its system. Furthermore, monitoring appropriate parameters may help to better define maintenance intervals which could increase efficiency of the entire system. However, particular attention should be paid to accurate measurements of the compressor flow and power.

Among the six main objectives of the project, performance, safety and maintenance were identified to be the most important. Performance is the key. It is achieved by operating compressor at appropriate conditions which could be closely monitored. Since data will be collected on the customers' site, it is crucial to ensure safe operation of the system taking into consideration the various environments the compressor may be subjected to. Maintenance should be kept to a minimum.
A functional model was deemed to be the most suitable tool to proceed with. At this stage, following consultations with the industrial partner, it was proposed that the best interest for the company would be if students work towards developing concepts for physical sensing and performance calculation. The industrial partner would concentrate on the collection and transmission of the output values.
The main engineering characteristics were drawn in a functional model format while the comprehensive list was used in QFD to identify relationship with the requirements of the project. Following the QFD exercise, it was identified that the main focus should be towards accurate measurements and calculation of following parameters; Mass Flow-Capacity, Torque, Temperature, Pressure and Power.

3 CONCEPTUALISATION

During the conceptual phase, the student team generated a number of concepts to obtain required performance values. A number of design tools were used to help in realisation of this phase including QFD, Morphological chart, decision making etc.

3.1 Conceptual Analysis

Parameters monitored by the system which need to be focused on, could be obtained either by sole use of sensing devices or by combination of mathematical modelling and sensing. Advantages of combined sensing and modelling allow use of simpler sensing methods such as monitoring just pressures and temperatures. This can significantly reduce overall costs of the monitoring system and allow general use in both, already installed and new compressors. Use of pure sensing will provide more accurate results with off the shelf solution but will increase costs of the system and will not be available for already installed compressors. Additionally some types of flow meters or power meters may not be possible to be installed even in the new systems. The company and students team decided to use a mixture of the two methods in order to produce concept variants for the monitoring system.
Functional models consisting of sensing devices and mathematical modelling were created for mass flow (Figure 2), power (Figure 3), and rotational speed (Figure 4).

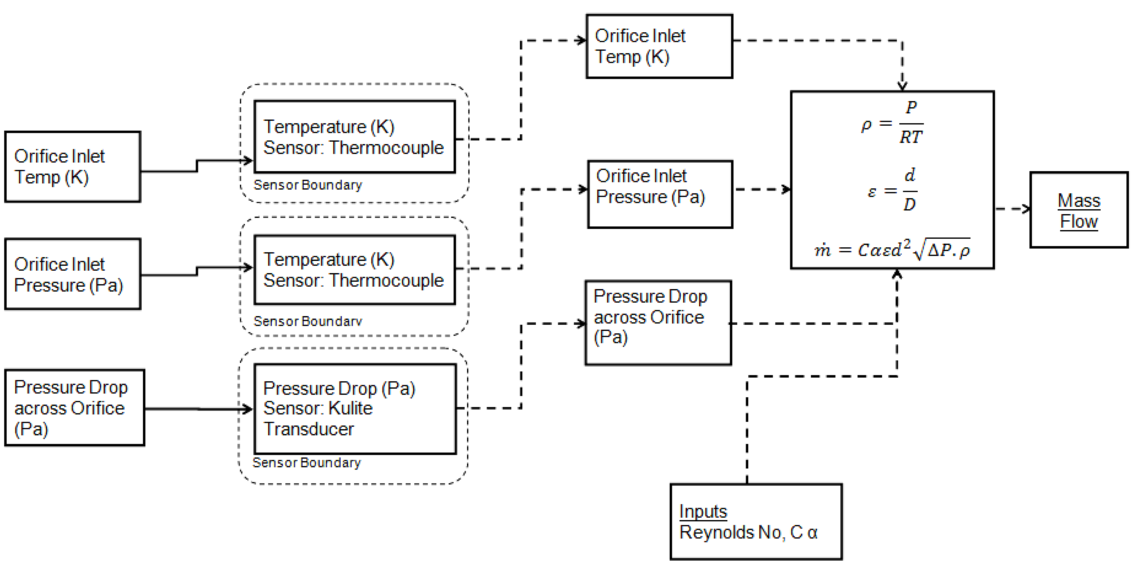

Figure 2. Functional model for the flow measurements

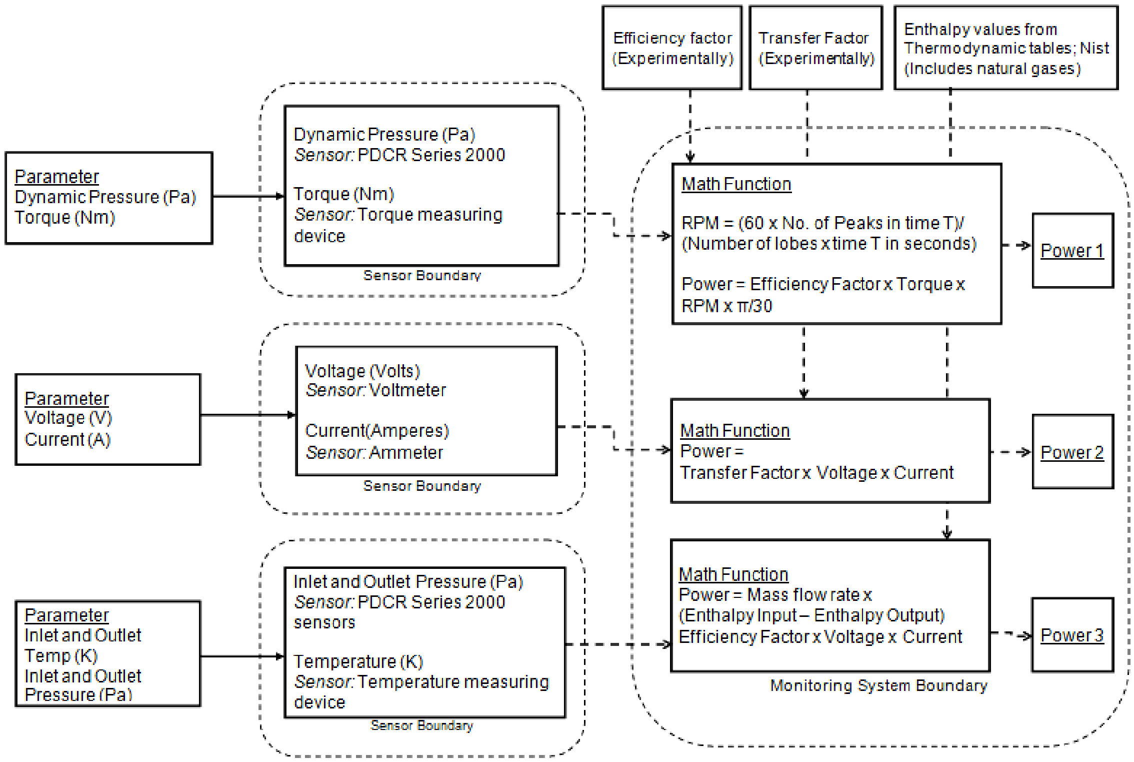

Figure 3. Functional model for obtaining power of the compressor system

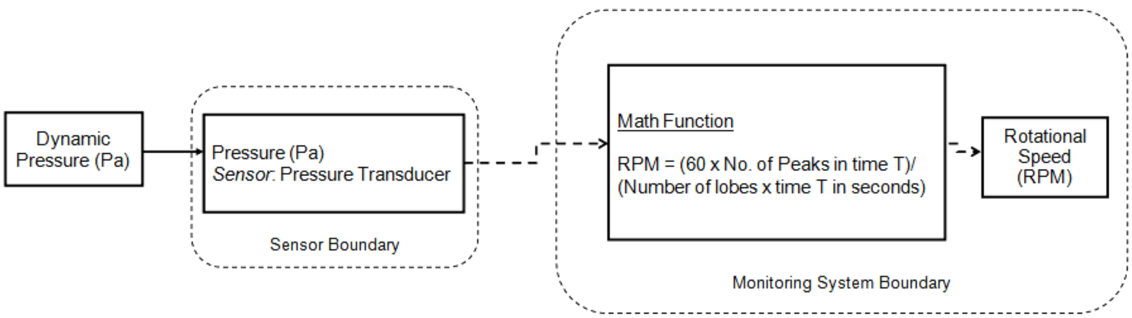

Figure 4. Functional model for measuring rotational speed

Three ways of computing compressor power were proposed, namely use of dynamic pressure and torque, voltage and current which is only possible for electrically driven compressors and by using mass flow rate and enthalpy.

Mass flow could be obtained by an orifice plate measuring temperature and pressure at inlet and outlet along with the pressure drop across the plate using thermocouples and a pressure transducer or by the hot wire insertion in the suction port. Both considered methods are possible just in case of known gas composition in the compressor.

Rotational speed is obtained by use of a high speed pressure transducer and counting pulses.

Using too many probing devices poses space issues and often is not allowed by the users of compressor systems.

Out of four generated concepts, two were fully instrumented and are therefore more expensive (Concept 1 and Concept4). They required installation of expensive thermal anemometer and torque meter which may require more frequent maintenance. Additionally, these can be used only in electric driven systems. In Concept 2, power computation was based on enthalpy change which excluded mechanical losses of bearings, seals and transmission. However it cannot be neglected and had to be modelled for this concept. The preferred Concept 3 used simple orifice plate for measurements of the mass flow.

A diagram of economical vs. technical values was constructed from the decision matrix to compare produced concept variants. Installation and maintenance costs were used for the economic criteria while accuracy and suitability to different compressor applications are associated with the technical criteria. It was identified that concept 3 was the optimal solution which could offer to the Company economically viable solution with accurate results to meet requirements.

4 PERSONAL EXPERIENCES OF STUDENTS

The group of students had little experience working in self-managed design groups before this project. This was their first attempt on a real engineering problem with an industrial partner which had to be performed with minimal supervision from academics. The design process proved to be a convenient means of learning design as well as self-managing the group still providing a concept for the industrial partner which might be worthwhile pursuing further in manufacturing.

By following the phases of the engineering design process the students gained an understanding of how a major engineering problem can be broken down into manageable sub-problems. This allowed a clear focus on individual tasks with boundaries of each stage clearly defined. In addition to this, the students were involved in solving a design problem which included various engineering disciplines such as electronics and control, which they had no chance to study before. The students also gained skills in systems engineering which allowed them to synthesise the various areas and integration of the overall problem and concepts into one. The students learned how the environmental constraints and safety regulations affect the mechanical systems how these need to be incorporated in product design. Additionally, cost and market analysis of the design were learned through use of graphical plots and their impact on design was evaluated and understood. They also gained experience on decision making skills based on the cost and market analysis which was carried out.

Another important aspect of the preparatory course for EGPR was to learn how to effectively and accurately communicate the design process and its technical aspects. This was done through technical drawings, report writing and sets of presentations that acted as design review stages. There were instances when incorrect information led to slight delays, however, students learnt effective methods of communication from this experience. It was crucial that the need for changes in requirements and constraints is understood properly. These changes were mainly attributed to the customers' needs; hence it was important to adapt design solutions accordingly. This was challenging particularly because of time constraints of this project which was performed in parallel with other subjects in the syllabus. It is this nature of this course which gave the students the ability to cope with all challenges under pressure and to achieve more effective learning in a short period of time. This enabled the students to learn new concepts, gain computational and theoretical knowledge faster, whilst working on other assignments and design projects. Similar conclusions were derived in the project which group of City University students had with the same Industrial partner two years ago [4].

One of the challenges for the inexperienced group of students was to identify appropriate and accurate research methods and resources for the project. The students came across vast amount of information available mostly on internet whose integrity was unknown. It was vital that the details obtained by such means were always cross referenced against other resources and confirmed with the industrial partner. This enabled the students to gain excellent research techniques and highly reliable methods which then proved to be effective for the preparatory course but also very useful in the main EGPR course.

Initially the group members struggled to grasp the nuances of screw compressors and the methods of control. However, the process proved that the research phase was essential for the design project and that misunderstanding of the problem would result in a failure of process in generating an effective solution.

Development of the team and the relationships within, allowed for each member to enhance their communication skills. As with all groups working on a project, unity is essential in keeping productivity high. Therefore all members always ensured discussions would remain constructive by respecting another viewpoint.

It is often the case that groups break down when a team is under pressure to deliver a task within a specified time. However in this course, time constraints and the motivation in self managed situation helped the group to improve time management skills through setting clear milestones and review points throughout the project. Communication through the Internet by means of email and audio/video protocols such as Skype® allowed team members to liaise anytime as urgent problems arose, paving the way for a speedy resolution before the following meeting. Additionally one of project reviews was performed over the videoconferencing system which added complexity but provided an opportunity for students to understand difficulties in such communication.

Each student felt that with this project they are better placed when beginning their careers in engineering companies. The task prepares each individual in understanding the problem to have the ability to contribute to the design process. Engineering products have increased with complexity and cost over the past years, pushing the need for efficient design teams essential to the success of the product within the time period allocated. This will be particularly important for the project that these students will undertake with five other universities in the EGPR course in the summer term of this year.

5 CONCLUSION

This project undertaken at City University, London by the group of undergraduate students lasted just over 10 weeks. It was a good opportunity for students to familiarise themselves with the engineering design process whilst working with on a real life problem with the industrial partner. The tools used within the design process were carefully chosen to ensure that the output meet all the requirements and needs of the industrial partner. The students faced a number of challenges including finding accurate solutions for measurement of mass flow and power.

Due to fairly limited time available at hand, only four concepts could be produced. At the end, the most promising concept which encapsulates relatively simple measuring techniques was proposed to the Industrial partner. It was agreed that depending on the compressor system a combination of the concepts would provide the best solution.

The competences and skills gained by the students during this project were invaluable as it was possible for the first time that this group of students both, learn and work professionally with an industrial partner. It is noted that despite severe time constraints, the students' knowledge of the design process expanded considerably. The university gained engineering links and marketing while the industrial partner benefitted from fresh ideas using a systematic design process from the students and potential future employees.

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