Systems Engineering Approach: Postgraduate Programme Bridging the Gap Between the Theory and Industrial Practice in Lift (Elevator) Engineering

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Keywords: Lift (Elevator) Engineering, Systems Engineering, Postgraduate Programme, Safety Standards, Design.

Abstract. The paper provides a comprehensive introduction to, and an appraisal of, a postgraduate Lift Engineering programme. The programme is based on systems engineering approach and has been designed to transfer the underpinning knowledge required for effective advanced engineering design, research and management in the lift (elevator) making and allied industries. The provision evolved from the distance learning programme which was originally developed following the introduction of the first edition of the European standard EN 81-1:1977. Some parts of the programme have been modified appropriately to reflect other national codes such as ASME/ANSI A17.1. The programme comprises the Masters - level course. The research degree programme offers then an opportunity for successful candidates to study towards PhD / MPhil. An example is discussed to illustrate how research-informed learning aids the solution of complex Lift Engineering design problems. The analysis demonstrates how practice, learning and research are integrated into the programme.

1 INTRODUCTION

In view of the present world-wide interest in the development of safe and cost-effective means of vertical transportation the importance of engineering education for technical staff employed within the (Lift) Elevator Industry cannot be overestimated. The principles underlying Lift Engineering involve a broad range of subjects including Electrical and Electronic, Mechanical, Civil and Production/ Manufacturing Engineering. A successful academic programme in Lift Engineering should therefore integrate those areas [1,2].

This paper presents an academic postgraduate programme that combine practice, learning and research in elevator engineering. The provision evolved from the distance learning programme which was originally developed following the introduction of the first edition of the European standard EN 81-1:1977. Some parts of the programme have been modified appropriately to reflect other national codes such as ASME/ANSI A17.1. The programme comprises the Masters - level postgraduate course which is outlined in the paper.

2 THE LIFT ENGINEERING PROGRAMME

2.1 MSc course structure and delivery

The Masters (MSc) course is composed of compulsory and elective/ designated taught modules, plus an independent, industry-based research study presented in the form of a dissertation [3]. The compulsory taught modules are concerned with Lift Applications Engineering, Codes and Standards and Management of Contracts, all of which are essential. Elective modules provide students with the opportunity to pursue their own specialization within the industry and currently include Lift Component Applications, Hydraulic Systems, Control Systems, Utilization of Materials, Dynamics and Vibrations and Vertical Transportation Systems.

The MSc is delivered in a distance learning regime. In this regime the emphasis is on learning rather than teaching. The tutorial team is staffed and supported by a combination of experienced educational practitioners, together with experienced practitioners drawn from the UK lift industry. The tutors fulfil the role of facilitators of learning. Furthermore, the acquisition of the skills of self-learning is a primary and specific aim of the provision. The tutorial team in collaboration with the lift industry has been involved with the design, development and operation of a Distance Learning course in Lift Technology since 1983. Thus, learning materials for the MSc course have been designed and are continuously revised for use by distance learning students building on and developing from the 35 years of operation of the distance learning provision.

2.2 MSc dissertation and research projects

Research projects form an integral part of the course and each candidate at his/her final stage of study is required to propose and justify a research topic as a subject of the dissertation. This involves the identification of research objectives, the selection of appropriate methods with regard to the research problem, the presentation of the research work plan and an initial review of relevant literature. Subsequently, after the proposal is accepted, the candidate manages his / her own time and activities to bring the project to a successful conclusion. The candidates have access to specialized literature and research resources at the University. The student maintains a chronological record of the work undertaken in pursuit of the project which is periodically submitted to his / her tutor. This forms an important element in compensating for the reduced face to face contact between student and tutor as compared with a similar, but full time student.

Over the last few years over seventy successful projects were completed and MSc dissertations submitted. They cover a broad range of topics and reflect both the students' interests and the industry needs demonstrating strong relationship between practice and theory across a number of elevator technology areas. Two book volumes with reviews of the MSc dissertations have been published by Elevator World [4,5]. The topics cover a broad range of problems such as the effect of building sway on elevator ropes, ventilation and passenger comfort, power comsumption, firefighting and evacuation, usage and utilizing lifts for the differently abled people, safety gear performance, code requirements for interfaces between building systems and elevator systems, accidents involving luggage trolleys and/or shopping carts on escalators .

2.3 Research degree programme

The research programme provides an opportunity for the MSc graduates to continue their studies towards higher research degrees (PhD/MPhil). The programme environment offers an opportunity for students to network with a variety of contacts through research seminars and conference events.

Each academic year commences with the annual Symposium on Lift and Escalator Technologies organized in conjunction with the Chartered Institution of Building Services Engineers (CIBSE) Lifts Group and the Lift and Escalator Industry Association (LEIA), This event provides opportunities for students, practitioners and engineers from industry and academia worldwide to network and discuss the latest training, education, research and innovation developments. The symposium event is now in its 9th edition and the next conference is taking place later this year, from 19th to 20th September 2018.

3 SELECTED TOPICS: LIFT BRAKING AND STOPPING

3.1 Electromechanical braking and emergency arrest

The issue of slowing and bringing the lift car safely to rest is one of the most important problems in the design of a lift installation. This problem is addressed in the MSc syllabus [3] in the context of the traction drive system and the relationships between braking, drive control and traction are comprehensively treated throughout the course learning materials.

This involves the electromechanical brake and the entire range of situations with which it might have to deal, including normal and emergency conditions, considering the interfaces and linkages between the brake and the control systems, and between the brake and the lift car. In accordance with EN 81-20:2014 [8], the electromechanical brake alone must be capable of stopping and holding 125% of the rated load. But even the most modern lift system will be required to stop under the action of electromechanical braking if there is an unconventional event such as the opening of the landing door whilst the lift is in motion, or an interruption of the power supply, for example [1].

However, the discussion of the issues above is predicated upon the assumption that the traction system remains intact and that deceleration of the system is achieved by a braking torque applied to the traction sheave. Thus, the dynamics of the stopping / arrest of the lift car are limited by the available traction. Therefore, it is necessary to investigate the ultimate systems for arresting uncontrolled motion by acting directly on the car.

The ultimate safety system to stop a lift car in the event of overspeed consists of the following elements:

- an overspeed governor set to trip at a pre-determined speed at least 115% of rated speed. An electrical trip should de-energise the drive and engage the electromechanical brake before the car speed, either up or down, reaches this tripping speed.
- a safety gear located on the car (and, in some circumstances, on the counterweight), which will arrest an uncontrolled overspeed in the down direction and
- a suitable device, such as a rope brake or sheave brake, which will arrest an overspeed in the up direction (or any unintended movement in either direction).

Fig. 1 shows the main components of a system for emergency arrest in the down direction [1]. An overspeed governor located in the machine room or in the upper part of the hoist way is connected to the safety gear system on the car by the governor rope. The governor rope is a complete loop, with both ends terminated on the safety gear system on the car, after passing around a loaded tensioning pulley in the pit. The two basic types of mechanical overspeed governor (rocking arm and pivoted bob-weight types) are shown in the diagram together with the three basic types of safety gear - instantaneous (type A) either cam type or captive roller, and progressive (type B). On the car, the governor rope is terminated at the top of the car and connected to the safety gear via a safety gear operating rod.

3.2 Lift car - safety gear performance analysis

Consider a simplified diagram of the car – safety gear interaction shown in Fig. 2(a). In the scenario considered here the car suspension failure is assumed. The car is represented by a rigid body of mass m acted upon by the safety gear braking force F_{sg}. If at the time instant t_1 the car has a speed of v_1 and at the time instant t_2 the speed is v_2 the application of the principle of work and energy [6] yields

$$\frac{1}{2}mv_1^2 + mgy_1 - F_{sg}\Delta y = \frac{1}{2}mv_2^2 + mgy_2 \tag{1}$$

where $\Delta y = y_1 - y_2$ is the distance travelled by the car when being slowed down by the safety gear actions and g is the acceleration of gravity (9.81 m/s^2).

Fig. 2(b) shows the results (velocity, position plots) of a drop test to examine the performance of a safety gear device to be installed in a lift car of mass m = 10207 kg [7]. In Fig. 2(c) the mean acceleration of the mass is shown. It is evident from the test results that during the test the free fall of the mass is arrested at the time instant t_1 ($\approx 2.1\,\text{s}$) and then over the time interval $\Delta t = t_2 - t_1 \approx 3.45 - 2.1 = 1.35\ \text{s}$ the car continues to descend at a near constant speed (of about 12.5

m/s). Thus, the braking force developed by the safety gear is of inadequate magnitude, and it is just large enough to balance the car weight ($F_{sg} \approx mg$). Thus, the safety gear needs to be re-designed.

The required braking force to decelerate the car from v = 12.5 m/s to rest can be determined from (1) by setting $v_2 = 0$ so that the following equation is obtained

$$\frac{1}{2}mv^2 + mg\Delta y - F_{sg}\Delta y = 0 \tag{2}$$

The braking force is then expressed as

$$F_{sg} = \frac{\frac{1}{2}mv^2 + mg\Delta y}{\Delta y} \tag{3}$$

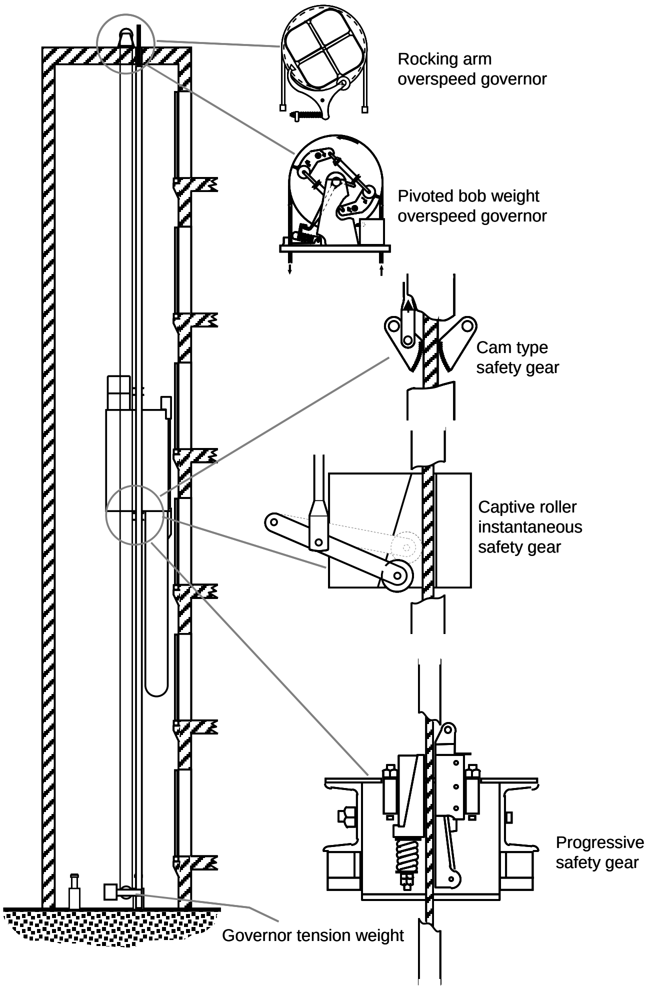
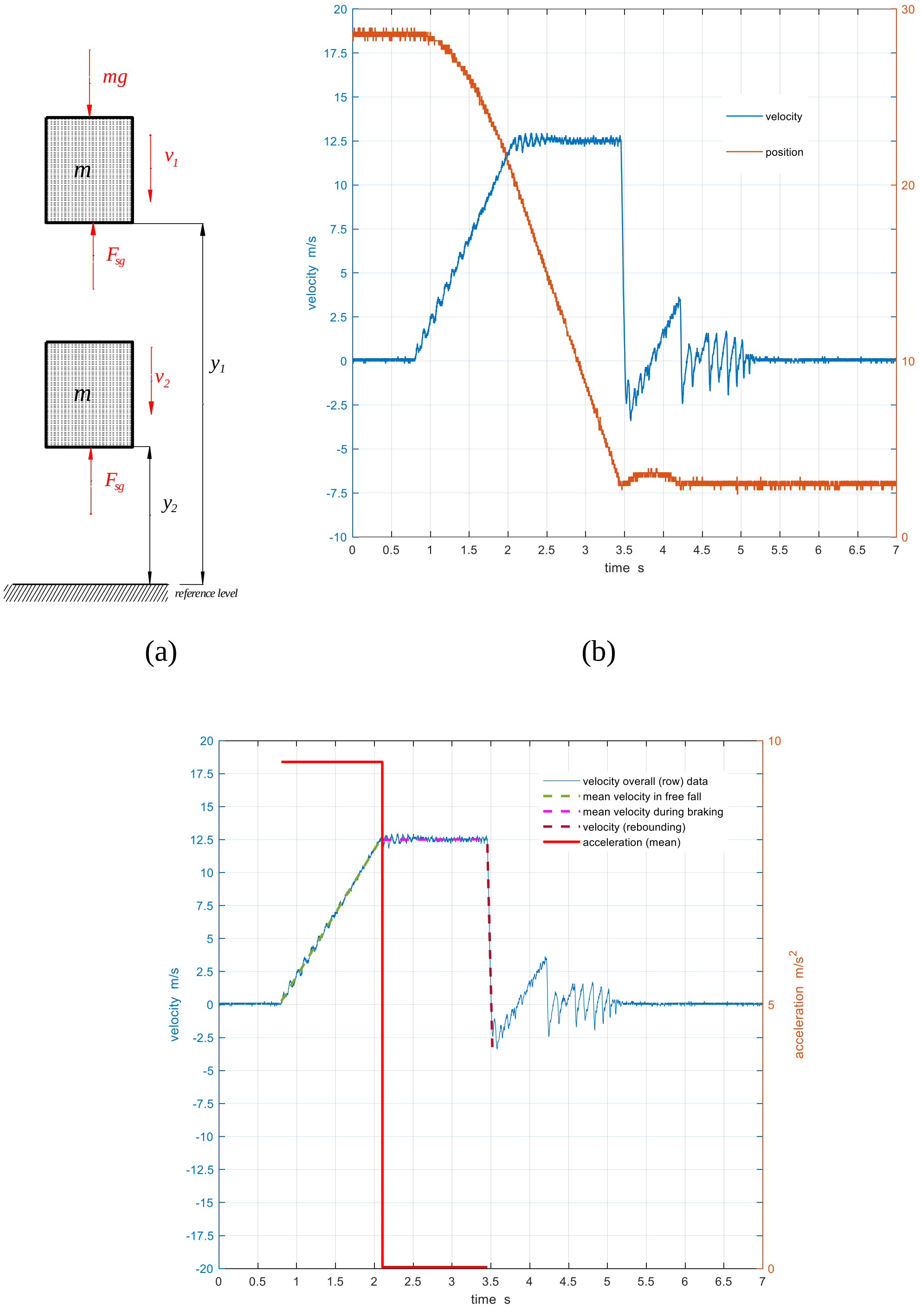


Figure 1 Safety gear – car system [1]

By using $\Delta y = v^2/2a$ in Eq. 3, where a denotes the deceleration rate, and setting the deceleration rate as a = 0.6g (as per the nominal deceleration requirement in EN 81-20 [8]) the required safety gear braking (friction) force is determined as 161.2 kN. During the test the braking force applied was about $F_{sg} \approx mg = 100.75$ kN. Thus, the required increase is significant and can be achieved by various means explored below.



(a) (b)

(c)

Figure 2 Safety gear action (a) simplified model; (b) test results (c) velocity – acceleration plots

For a progressive (Type B) safety gear, the braking forces were investigated in one MSc dissertation [4,9] extracting data from drop test results of a family of safety gears and comparing these with the literature and other safety gears. The braking force is generated by the interaction of the braking surfaces (gibs) of the safety gear and the guide rail. To a first approximation, this braking force for a single safety gear can be modelled as:

$$F_{sg} = 2\mu R \tag{4}$$

where R is the reaction force between the braking surfaces and the guide rail and μ is the coefficient of friction between the sliding surfaces. The factor of 2 comes from the two pairs of surfaces in contact on a single guide rail. Thus, in looking to increase the braking force of the safety gear, there are two avenues to investigate:

- Increasing the coefficient of friction, μ. However, μ is determined by the selection of materials for the safety gear gibs and machined steel guide rails. A significant increase could be made by changing to materials used e.g. as used in automotive brake pads and by changing the design.

- Increasing the reaction force (generated by springs) consistent with the design of the safety gear e.g. limitations from the strength of the safety gear housing, heating of the braking surfaces, and avoiding excessive damage to the sliding surfaces which would tend to limit the reaction force used.

This is not to imply that the value of μ is constant. It has been documented at least as far back as 1865 that the coefficient of friction for railway brakes was lower at higher running speeds and was also dependant on the reaction force R. These dependencies were recognised in the lift literature and are implied by numerous progressive safety gear drop test results. The MSc dissertation studied this speed dependence where the variation of the coefficient of friction with rubbing speed for a single gib/ guide rail interaction was modelled as:

$$\mu = \mu_0 e^{-cRv} \tag{5}$$

where v is the sliding speed, μ_0 is the coefficient of friction when $v = 0$, R is as before, c is a constant. After analysing results, a more refined model was suggested.

This research project was typical of many MSc dissertation projects as it was a piece of research based on a study of application design so involved close collaboration with the industry and yielded not only a useful academic result but also a practical one; one of the outcomes of the study was that the safety gear design studied had its nominal load increased for use at lower tripping speeds.

4 CONCLUSIONS

The Lift Engineering provision has been developed to integrate three key elements: practice, learning and research. It forms a complete provision for lifelong learning bridging the gap between the theory and industrial practice. The provision involves a modular MSc level course taught through distance learning. The taught modules cover a broad range of areas relevant to the theory and practice in the field of lift technology. In order to progress to the dissertation stage a student must achieve a pass in each of the compulsory modules and the two elective modules (at the first or second attempt). Subsequently, the student is required to undertake advanced independent study leading to the MSc dissertation which is considered essential to achievement of the award. The course is tailored to the needs of those who are employed in the lift manufacturing and allied industries and is supported by the Lift and Escalator Industry Association. Flexible structure of the course and distance learning regime of study minimizes time away from work and benefits both the employer and the employee. Research project forms an integral part of the course and gives students an opportunity to conduct an independent study making use of the skills and knowledge acquired elsewhere in the course. The programme offers an opportunity for successful candidates to study towards PhD/MPhil research degrees.

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BIOGRAPHICAL DETAILS

Stefan Kaczmarczyk is Professor of Applied Mechanics and Postgraduate Programme Leader for Lift Engineering at the University of Northampton. His expertise is in the area of applied dynamics and vibration with particular applications to vertical transportation and material handling systems. He has been involved in collaborative research with a number of national and international partners and has an extensive track record in consulting and research in vertical transportation and lift engineering.

Rory Smith has over 49 years of experience in all aspects of the lift industry including sales, installation, maintenance, manufacturing, engineering, research & development. He has worked for ThyssenKrupp Elevator for the last 23 years. Prior to becoming involved in ThyssenKrupp's Internet of Things, he was Operations Director, ThyssenKrupp Elevator Middle East. His scientific interests include, operations management, high rise - high speed technology, ride quality, traffic analysis, dispatching. To date he has been awarded numerous patents in these areas and has many pending patents.

Nick Mellor has worked for the UK’s Lift and Escalator Industry Association (LEIA) as Technical Director and Managing Director since 2012 and has been in the industry for 26 years. Nick was in the inaugural cohort of the MSc in Lift Engineering at Northampton. More recently, as an Associate Lecturer, he has done some tutoring on the MSc.