Lift Engineering Design Challenges from the Postgraduate Programme Perspective

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Abstract. This paper describes the background and concept of a postgraduate lift engineering programme, comprising an MSc Lift Engineering and PhD/ MPhil, aimed at those involved in lift engineering and related fields. The MSc in Lift Engineering integrates a systems engineering approach with other modules such as a study of global codes and standards, contract management, elective modules and a dissertation. Solutions to a design challenge arising from the results of safety gear drop tests are drawn from the systems engineering approach of the learning materials and in the context of an earlier MSc dissertation. Newly presented data from drop tests is analysed to provide information on the variation of safety gear friction with rubbing speed and this is compared with the results from earlier dissertation research work.

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 which comprises a Masters level postgraduate course combining practice, learning and research in lift (elevator) engineering. The programme is described in section 2 elaborating earlier work [10]. The link between programme content and research is illustrated by the examination of selected topics in section 3. The systems engineering approach to the behaviour of a lift during safety gear operation is extended by examining research work undertaken as part of the programme. This research provides the context for further research which is presented here.

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 with students typically employed within the wider lift (elevator) industry. This allows the practice of their employment to inform their choice of elective modules and the direction of their research. The flexible structure of the course and distance learning regime of study minimizes time away from work and benefits both the employer and the employee.

In this regime the emphasis is on learning rather than teaching. The assessment structure of the MSc consists of numerous self-assessment questions (SAQs) in the learning materials to aid learning, through assignments posing design challenges or encouraging deeper understanding of an important aspect, to a case study module which combines assessment of lift applications engineering, codes and standards, and contracts management. In order to progress to the dissertation a student must achieve passes in each of the compulsory modules and two elective modules (at the first or second attempt).

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

Having achieved a pass for all the required compulsory and elective modules, the student is required to undertake advanced independent study leading to the MSc dissertation. The 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. Research topics chosen typically reflect students' interests and draw on the learning from the modules undertaken. Each candidate is required to propose and justify a research topic as a subject of the dissertation.

The dissertation module 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. A research proposal, addressing these elements, must be submitted to the tutorial team for approval before the student can proceed with the research work. Further development of the research proposal might be required to meet the needs of Masters level research and to be approved.

Subsequently the student manages their own time and activities to bring the project to a successful conclusion. Students have access to specialized literature and research resources at the University. The students maintain a chronological record of the work undertaken in pursuit of the project which is periodically submitted to their tutors. This forms an important element compensating for the reduced face to face contact between student and tutor as compared with a similar, but full time student.

Once completed, the submitted dissertation is assessed by the tutorial team including a viva voce. It is not unusual for the path of the research to diverge from that originally intended. Indeed, often objective research might not deliver the outcomes expected. It would be expected that the student would be able to justify such changes. Successful completion of the dissertation module completes the MSc in Lift Engineering.

Over recent years over seventy successful projects have been 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 lift (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, 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 is taking place from 19th to 20th September 2018.

3 SELECTED TOPICS

3.1 Background

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. The 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 may be limited by the available traction. Therefore, it is necessary to investigate the ultimate systems for arresting uncontrolled downwards motion which consist 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 reaches this tripping speed and
- a safety gear located on the car which will arrest a free-fall or overspeed in the down direction.

Also suitable devices are required to arrest an overspeed in the up direction (or to ensure that the speed does not exceed that for which the counterweight buffer is designed) or any unintended movement with doors open in either direction with their own detection and actuation means.

Figure 1 shows the main components of a system for emergency arrest in the down direction [1]. An overspeed governor located above 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.

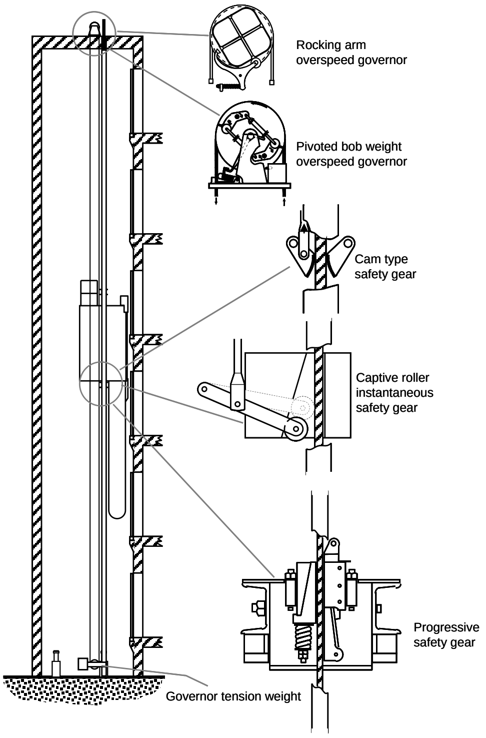


Figure 1 Safety gear – car system [1]

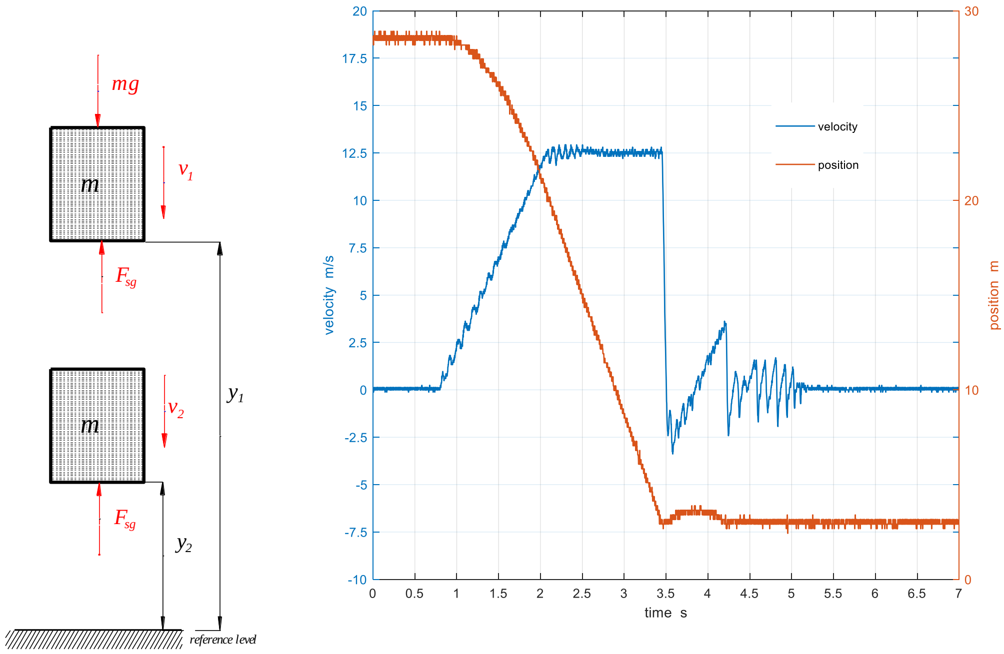
3.2 Lift car - safety gear performance analysis

Consider a simplified diagram of the car – safety gear interaction shown in Figure 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).

Figure 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 = 10270 kg [7]. In Figure 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 ($\approx 2.1\,\mathrm{s}$) and then over the time interval $\Delta t = t_2 - t_1 \approx 3.45 - 2.1 = 1.35$ 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.



(a) **(b)**

Figure 2 Safety gear action (a) simplified model; (b) test results: velocity - position plots

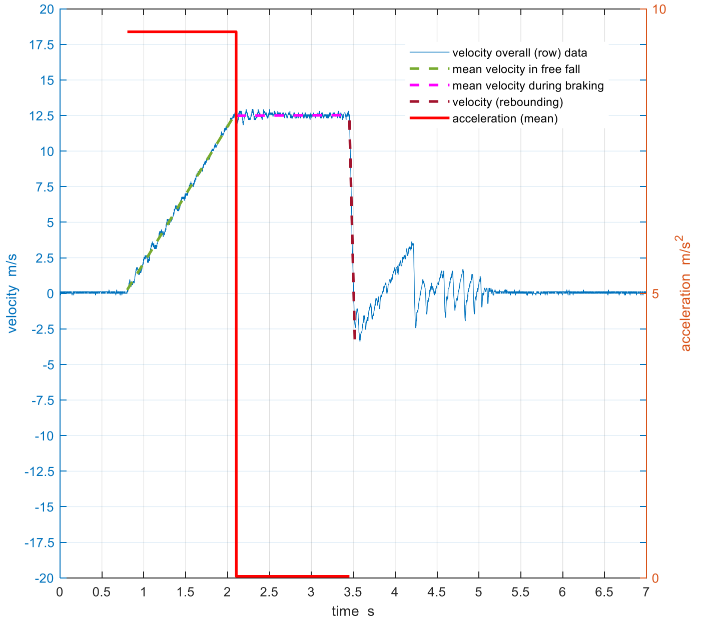


Figure 2 (c) Safety gear velocity – acceleration plots

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

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

The braking force is then expressed as

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

By using $\Delta y = v^2/2a$ in Equation 3, where a denotes the deceleration, and setting the deceleration as a = 0.6 g_n (the nominal deceleration required 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 approximately $F_{sg} \approx mg$ = 100.75 kN. The required increase is very significant and could potentially be achieved by various means explored below.

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:

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

where N is the number of braking surfaces (2 in the case of a single gib to each side), R is the reaction force between each braking surface (generally produced by springs and the guide rail and μ is the coefficient of friction between the sliding surfaces.

Thus, in looking to increase the braking force of the safety gear, there are three avenues to investigate.

- Increasing the number of braking surfaces (gibs), N, along with reaction springs etc. However, to increase the number of braking surfaces in each safety gear would be a significant design change as it would also increase the number of reaction springs and hence the clamping force for which the safety gear housing must be designed and the stopping force transmitted through the safety gear housing.
- 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 the materials used e.g. from conventional hardened steel gibs to a material as used in automotive brake pads and by changing the design. This would also result in significant increase in the stopping force to be transmitted through the housing requiring a review of the safety gear design.
- Increasing the reaction force (generated by springs), R, 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 pressure and damage to the sliding surfaces which would tend to limit the reaction force used.

Within the context of the MSc in Lift Engineering, these potential changes would all require significant design changes of the safety gear which could be further considered in the Lift Component Applications module of the MSc in Lift Engineering.

3.3 Variation of coefficient of friction with speed

A further drop test result was examined as shown in the speed plotted against time Figure 3. This shows two stages:

- The free-fall of the test mass shown in the light blue trace “acceleration” in Figure 3. During this period, speed increases linearly with time as expected but with a gradient of 9.5385 m/s^2 as shown by the linear trend-line fitted to this part of the speed plot. The extent to which this is less than the acceleration due to gravity, 9.8067 m/s^2, is presumed to be related to friction of the guidance system and other loses.
- The stopping phase when the safety gears grip the guide rails and bring the test mass to rest shown in the dark blue trace “deceleration” in Figure 3. During this phase, the reduction in speed is clearly not linear – the acceleration is shown by the gradient of the plot which increases steadily from tripping to be a maximum as the speed reduces to zero. This is evidenced by a trend-line with second order polynomial fitting the speed graph extremely well.

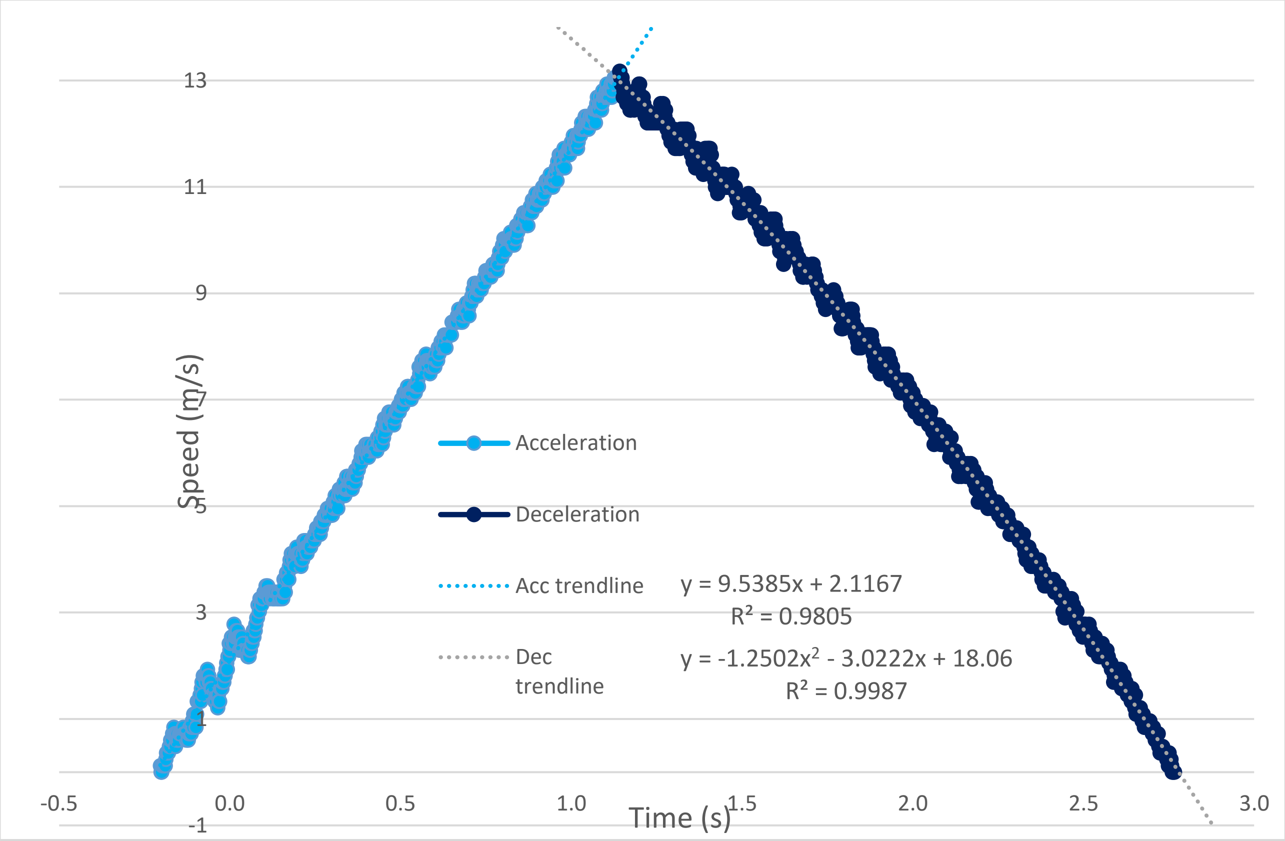


Figure 3 Drop test speed profile

In equations 1, 2 and 3, the safety gear force, F_{sg}, was treated as constant or an average over the stopping phase. Since for the free-fall of the test mass, *m*, it is clear that the acceleration, *a*, varies then it is clear that safety gear force varies and can be found by taking the slope of the speed plot:

$$F_{sg} = m\left(g_n + \frac{dv}{dt}\right) \tag{5}$$

Using equation 3 to calculate a value of the coefficient of friction, μ, allows this to be plotted against sliding speed as shown in Figure 4.

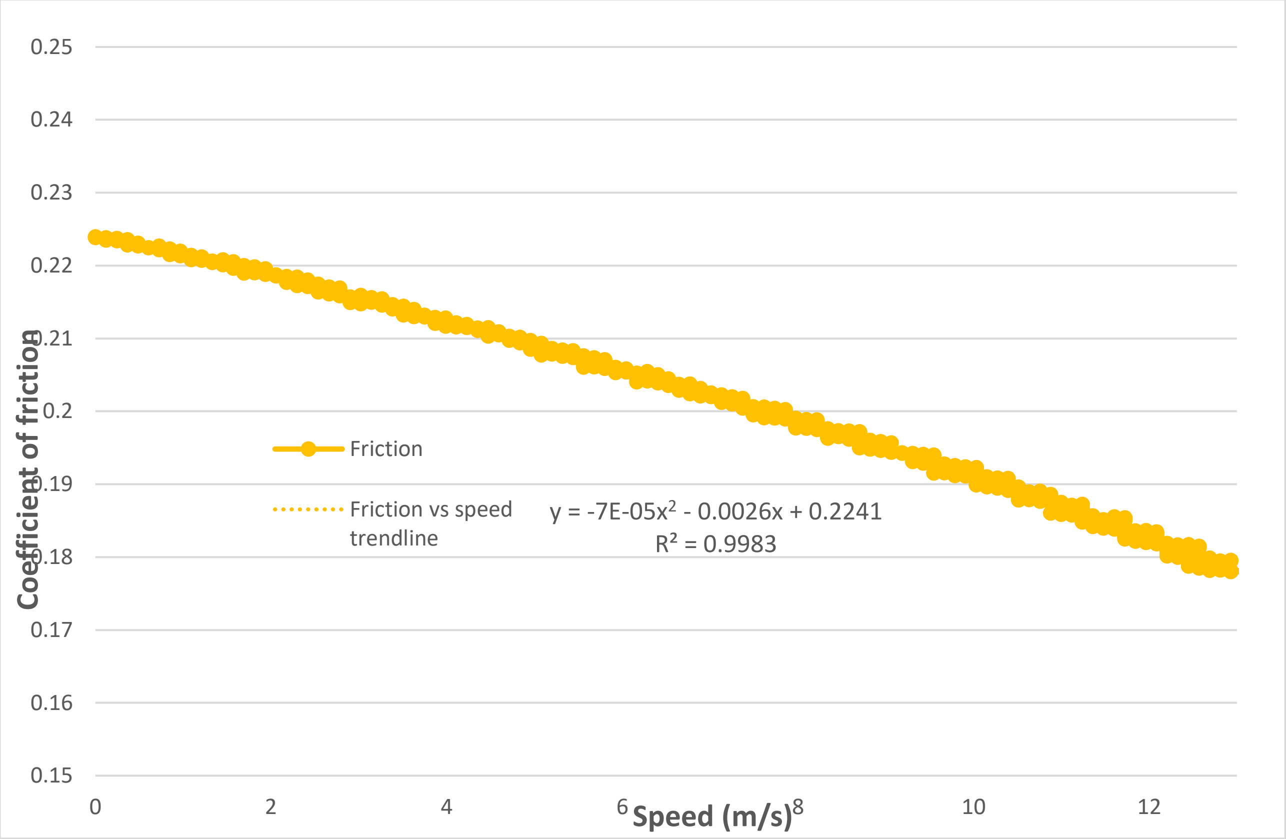


Figure 4 Coefficient of friction vs sliding speed

Figure 4 shows a clear reduction in the coefficient of friction as sliding speed increases; with a 20% reduction from zero speed to 13 m/s. As such, it can be seen to be much less speed-dependent than the safety gears studied as part of the MSc dissertation [4, 9], especially over the very wide speed range of the safety gear. Indeed, one of the design objectives of a high-speed safety gear of this type is to limit the speed-dependence of the braking force to within acceptable limits as in this case.

Variations in the value of μ have been documented at least as far back as 1865 with the coefficient of friction for railway brakes being lower at higher sliding speeds and also dependant on the reaction force R. These dependencies were recognised in the lift literature, were implied by numerous progressive safety gear drop test results, and were studied by an MSc dissertation [4, 9]. 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:

$$\mu = \mu_0 e^{-cRv} \tag{6}$$

where v is the sliding speed, μ_0 is the coefficient of friction when $v = 0$, R is as before, c is a constant.

Such a curve would not be as good a fit as the second order polynomial trend-line shown in Figure 4.

This research project investigating variations in friction arose from a practical problem encountered previously with the operation of safety gears. It was undertaken partly to investigate aspects of safety gear performance and so was typical of many MSc dissertation projects as it was based on a study of application design. The project yielded not only a useful academic result but also a practical result; 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 since the research evidenced higher braking forces at lower speeds.

The research project also informed the study of codes and standards which must balance ensuring a minimum braking force at tripping with limiting the maximum acceleration. For this reason, EN 81-20 specifies average the retardation for progressive safety gears in terms of free fall of the car with rated load to lie between 0.2 g_n and 1 g_n. Whether the margin of 0.2 g_n is sufficient in all cases is a moot point. So issues which arise from the selection of safety gear is the selection of safety gear and the maximum allowed variation in empty car weight (as has been discussed elsewhere).

4 CONCLUSIONS

The Lift Engineering provision has been developed to integrate three key elements: practice, learning and research. The programme includes a modular MSc 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. The student then undertakes an advanced independent study leading to the MSc dissertation.

The relationship between practice, learning and research has been illustrated with an example of a practical design problem on uncontrolled movement downwards, the treatment in the course materials and theory under-pinning the design of safety gears informed by a previous MSc dissertation. Data from more recent safety gear tests has been examined in the context of earlier MSc dissertation work.

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BIOGRAPHICAL DETAILS

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 since 1992. Nick was in the inaugural cohort of the MSc in Lift Engineering at Northampton. More recently, as an Associate Lecturer, he has tutored on the MSc. He sits on the BSI lifts committee MHE/4, working on the development of British Standards in the lift and escalator fields, and a number of CEN TC10 and ISO TC178 working groups including those for lift operation in the event of fire.

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.