Institution: University of Central Lancashire

Unit of Assessment: 15 General Engineering

Title of case study:

Applications of threaded-fastener research leading to improved plant and transportation safety

1. Summary of the impact (indicative maximum 100 words)

This case study outlines how research into the frictional behaviour of nuts and bolts (threaded fasteners) has found commercial applications and contributed to the improved safety of transport systems, industrial plant and equipment. A number of significant impacts have developed from a long-term research association between this UoA and the company Bolt Science, based in Chorley, Lancashire. Drawing on UCLan-based research, training materials have been developed by Bolt Science and delivered globally to encourage the safe and correct use of threaded fasteners in the engineering industry. Bolt Science have drawn on research conducted at UClan to inform a major accident investigation by the Rail Accident Investigation Branch as well as solutions to problems in other engineering applications.

2. Underpinning research (indicative maximum 500 words)

Underpinning research/context

This UoA has developed a close research association with the company Bolt Science of Chorley, Lancashire. Bill Eccles (now Dr Eccles) undertook his Ph.D on a part-time basis (July 2003-August 2010) in conjunction with Prof Ian Sherrington (Director of Studies) and co-supervisor Prof. Arnell. Eccles was during this period, and remains, Managing Director of Bolt Science which has been operating since 1992 providing training, software and consultancy on a global basis to manufacturing primes including: [Material redacted].

Key investigators and underpinning research

The key investigators in this project were the PhD candidate (Bill Eccles), Director of Studies (Prof Sherrington) and co-supervisor Prof Arnell. The most significant aspects of this research were investigations in two areas: (1) the effects of repeated tightening of threaded fasteners and (2) studies to investigate the loosening characteristics of prevailing torque nuts. Both of these studies led to significant insights into practical problems which plague commercial applications of these components in almost every engineering application conceivable.

Insights and findings

The first part of the study of critical importance was an investigation into the effects of repeated tightening of zinc plated threaded fasteners. This study showed that thread damage occurring during repeated tightening of these fasteners had a dramatic effect on the friction coefficient between the nut and bolt. In practical applications, devices which measure the tightening torque are used to establish whether threaded fasteners are correctly installed by inferring the bolt preload from the tightening torque. During repeated re-tightening, thread damage causes increased friction coefficients which means that an increasing proportion of the measured tightening torque is required to overcome friction leading to reduced bolt preload for a given tightening torque. This paper showed that after re-tightening five times the joint clamp force could be reduced to around 50% of that obtained at initial tightening (1). This can significantly reduce the integrity of bolted joints in maintenance operations and is one of the factors responsible for the cause of many major accidents.

A second original and commercially significant part of this research, investigated vibration induced loosening of threaded fasteners, an effect commonly referred to as “self-loosening”. It studied prevailing torque nuts, devices which contain special adaptations intended to prevent further bolt rotation and complete separation of the nut and bolt in instances where bolt pre-load in lost because the nut becomes loose. Commonly these adaptations consist of a small polymer insert

which provides increased friction to prevent the nut freely rotating on the bolt thread. These devices are extensively used in the belief that they prevent separation of the nut and bolt in safety-critical applications. However, it has frequently been found in practice that separation does occur leading to failures which can be both very costly from a financial perspective and may lead to loss of life. Prior to this study the reasons for separation were not clearly understood. Separation had not been observed in laboratory testing or in tests designated by standards for this purpose, such as the commonly used DIN standards, employing the Junkers Test apparatus. Our study demonstrated separation under practical testing for the first time and presented a theoretical model to determine the conditions under which loosening and separation would occur under both constant and intermittent axial load (2).

3. References to the research (indicative maximum of six references)

(1)* Eccles, W., Sherrington, I., Sperring, T., "Changes in friction coefficients during repeated tightening of zinc plated threaded fasteners". Tribology International 43 (2010) pp 700 – 707.

(2)* Eccles, W., Sherrington, I., Arnell, R. D. "Towards an understanding of the loosening characteristics of torque prevailing nuts". Proc IMechE Part C 224(2) (2010) pp 483 – 495.

* Best indicating quality of underpinning research

4. Details of the impact (indicative maximum 750 words)

The correct use of threaded fasteners is a critical element in health and safety, environmental protection and sound economic operation of plant and equipment and we are committed to distributing our expertise on this topic, particularly with a view to accident prevention. This UoAs close working relationship with Bolt Science is both longstanding and on-going and we are co-partners in developing a campaign which aims to highlight the outcomes of this research to an even wider commercial audience through the IMechE. Some details of this work has already been highlighted in trade press (1) and on the Bolt Science web site (2), but the main significance of the research is that it has informed commercial and industrial practice through the training and consultancy activities of Bolt Science.

Consultancy Activity:

Not all consultancy activities can be revealed here due to the nature of confidentiality agreements between clients and Bolt Science. However, three Case Studies of consultancy activities which highlight the significance of the knowledge gained during the research cited are given below.

Consultancy 1: Greyrigg Rail Accident Enquiry / Network Rail

In February 2007 a Virgin West Coast Pendolino service suffered a serious derailment in a fatal accident at Greyrigg, Cumbria during a journey from London Euston to Glasgow. In a Public Inquiry in 2011 the cause of the accident was traced to the condition of a "stretcher bar" in points at a "crossover" which had nuts that had become detached from the bolts. The derailment was a direct result of the failure of the bolts/nuts to hold the rail structure together.

Former PhD student Bill Eccles (as Bolt Science) acted as a consultant to the Rail Accident Investigation Branch (RAIB) and then subsequently to the Office of Rail Regulation to assist in establishing the root causes of the accident and assessing the effectiveness of proposals to rectify the issues on the rest of the points in the rail network. This involved working with these organisations completing analyses to determine the structural integrity of the joints and explaining, quoting when appropriate published research, the cause of the joint failures. Bill Eccles was also requested to look at the proposals to implement changes to the rail network to prevent a recurrence of the failure. Prevailing type nuts were on the original installation and the research cited above in (2) provided an explanation of why these nuts became detached from the bolts. The research in (2) above was also used to guide the selection of a locking fastener to be used in this application by Network Rail to prevent a recurrence of the accident. [Material redacted]

Consultancy 2: Electricity Supply Board (ESB) for Ireland

ESB use special four wheel drive [Material redacted] trucks for the maintenance of the electricity network in Ireland. For a number of years there had been issues with the wheel fixing. Due to the failure of the wheel fixing, the wheels can become detached leading to significant risk to the occupants of the vehicle as well as other road users. This was an on-going problem for a number of years with the manufacturer contesting that it was a maintenance issue. There was strong evidence to indicate that relative movement has occurred on some vehicles resulting in wear and failure of the wheel bolts. The manufacturer's recommendation included a specific torque value applied to dry nuts.

Based upon the research completed at UCLan and cited in (1) above it was recognised that repeated tightening of the same nut would result in a loss of bolt load due to frictional changes. Tests were completed to investigate the effect based upon the methodology from the UCLan research. The tests show that without any lubrication applied, there is a significant drop off in the load provided by the bolt for a given tightening torque. The drop off in the clamp force is significant, with the nut dry, by the 20th tightening the bolt load was a third of the first tightening. To prevent recurrence of the problem, lubrication of the nuts is now being conducted together with an increase to the tightening torque specification.

Consultancy 3: [Material redacted]
A number of cases of wheel detachment have occurred on a [Material redacted]. Based upon anecdotal evidence the wheel detachment generally occurred following the wheel being removed and re-secured. The existing bolts had a 60° cone connection with an electro-zinc plated (EZP) finish. Based upon the findings of the UCLAN research cited in (1) above, it was suspected that the use of an EZP finish would lead to an increase in friction when the bolts were re-tightened and a subsequently drop-off in the clamping load provided by the bolts. Subsequent tests proved that this was the case. To resolve the problem the fastener finish was changed to a zinc flake finish with a dry lubricant top coat. The tightening torque was also adjusted. The new finish had a lower and more repeatable friction characteristics which together with the modified tightening torque allowed a doubling in the load provided by the bolts. This was implemented as a service fix and onto new production. [Material redacted].

Training Courses:
One of the main activities of Bolt Science in to deliver training courses to engineering practioners and decision makers worldwide. Some of this training is delivered on a confidential basis, but customers include: [Material redacted].

The training courses are generally delivered to Engineers and in particular, Design Engineers, working in organisations that are end users of fasteners. Since January 2010 approximately 40 training courses have been completed to roughly 600 Engineers.

[Material redacted].

5. Sources to corroborate the impact (indicative maximum of 10 references)

(1) Bill Eccles “The loosening of Prevailing Torque Nuts”. Fastener and Fixing Magazine Issue 60 (November, 2009) pp 96 – 97.

(2) http://www.boltscience.com/pages/vibloose.htm

[Material redacted].