Institution: University of Bristol		
Unit of Assessment: 12) Engineering		
Title of case study: Innovative chain technology is adopted commercially, saves energy and wins cycling gold medals		
Period when the underpinning research was undertaken: 2000 - 2019		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s):	**Role(s) (e.g. job title):**	**Period(s) employed by submitting HEI:**
Stuart Burgess	Professor of Engineering Design	09/1997 - present
Jason Yon	Lecturer in Electromechanical Systems	11/2011 - present
Richard Lock	Research associate	01//2012 – 05/2015
Robert Wragge-Morley	Research associate	04/2016 – 12/2017
Period when the claimed impact occurred: 2014 - 2020		
Is this case study continued from a case study submitted in 2014? No		

1. Summary of the impact

High efficiency chain drive technology developed at the University of Bristol has been commercialised by Renold Chain [text removed for publication]. Improved industrial chains are being used in more than 90 countries, reducing power losses by up to 50%. In addition, new chain testing technology deployed at Renold Chain makes it practical, for the first time, to test very large chains. The British Olympic Cycling Team have adopted the new chains, which helped them to win six gold medals in the 2016 Rio Olympics. The technology was widely publicised at the time, reaching millions of people through TV, radio and publications. Extensive public outreach has been carried out through high-profile events, including the 2017 Royal Society Summer Science exhibition.

2. Underpinning research

Since January 2000, Renold Chain funded research into chain technology at Bristol University including supporting the funding of four PhD students and two post-doctoral researchers [i]. The purpose of the research has been to gain a fundamental understanding of the parameters that lead to better performance of roller chains in terms of power transmission efficiency and wear.

The research has included mathematical modelling of power transmission efficiency [1-4] the development of chain testing rigs [4-5] and generation of wear and efficiency data on 0.5-inch and 0.375-inch pitch chains [6].

Development of ultra-high accuracy test rigs

In order to optimise the design of chains for transmission efficiency, it is vital to obtain accurate test data. However, this is very challenging because traditional test rigs have several sources of power loss that are comparable to that of the chain. This makes it difficult to isolate accurate measurements of chain losses. To meet this challenge, highly innovative ultra-high accuracy test rigs were developed in 2014. The two most innovative test rigs are shown in Figure 1 and make use of a pendulum concept.

The invention of the pendulum test rigs (Figure 1) represented a major breakthrough. These rigs involve a completely new and innovative way of measuring efficiency using a decaying pendulum mounted on precision knife-edge bearings. The decay of the pendulum is monitored with a high precision laser system and the profile of the decay gives insight into the type and level of friction in the system [5]. The pendulum test rigs have been shown to be the most accurate rigs for measuring chain transmission efficiency and can achieve accuracy levels of

transmission efficiency of 0.012% [5]. This is nearly an order of magnitude higher than previous rigs [5]. The new technology also enables testing to be carried out with lower power requirements and over shorter time scales.

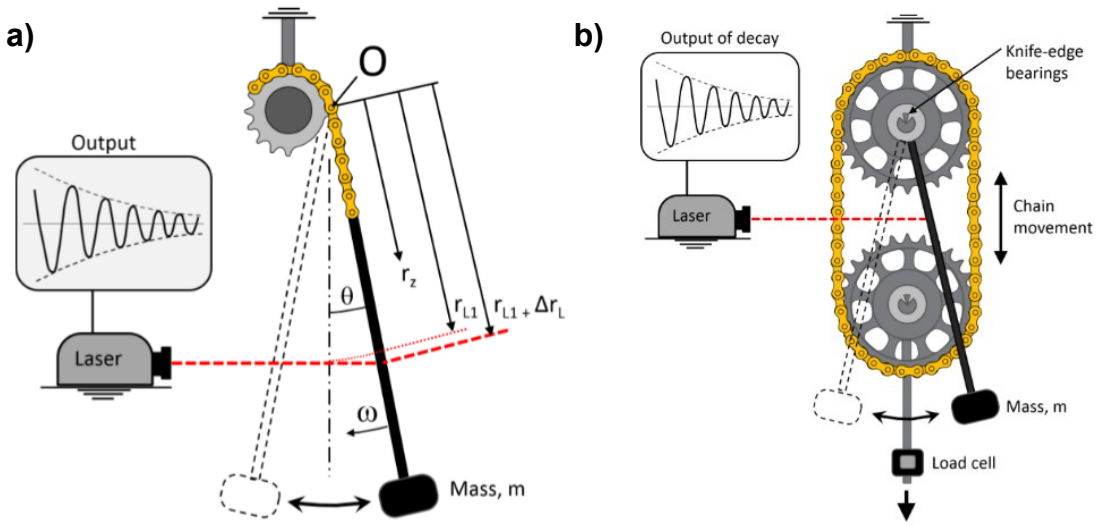


Figure 1. Schematic of single link (a) and dual sprocket (b) pendulum test rigs

Development of ultra-high efficiency chains

The new modelling [1-3], and testing procedures [4-5], have enabled researchers to gain many new insights into the relationship between geometry, material properties and transmission efficiency [5]. The research conducted on the new test rigs highlighted various trade-offs in chain geometry. For example, whilst smaller pin diameters (in the chain joints) have lower friction forces, smaller pin diameters also lead to higher contact pressures and higher coefficients of friction. The optimal diameter can be determined using the test rigs. Novel new geometries were designed that minimized friction in the chain and hence maximised transmission efficiency.

There were also new developments in material coatings and lubrication. The chain has a specially treated pin and bush to improve efficiency and reduce wear. The side plates are precision-formed and holed, before they are pre-stressed and the plates are then nickel-coated before assembly to prevent corrosion.

These innovations have reduced the power loss in chain drives by typically 50%, thus improving transmission efficiency from typically 96% to 98% [5]. This halving of power loss produces very significant improvements in performance not just in terms of energy consumption and but also wear life and associated maintenance costs.

National Award

In November 2019 Professor Stuart Burgess was awarded the premier award of the IMechE – the James Clayton Prize and GBP10,000 - for making an outstanding contribution to mechanical engineering science in 2019 [a]. The work on chain drives was a key reason for the award.

3. References to the research

[1] Lodge C, **Burgess SC**, A model of the tension and transmission efficiency of a bush roller chain, *Proceedings of the Institution of Mechanical Engineers Part C, Journal of Mechanical Engineering Science,* 216, 385-394, 2001. DOI:10.1243/0954406021525179

[2] **Burgess SC,** Lodge C, Optimisation of the chain drive system on sports motorcycles, *Sports Engineering,* 7, 65-73, 2004. DOI:10.1007/BF02915918

[3] Lodge C, **Burgess SC**, An investigation into the selection of optimum chain and sprocket size, *Journal of Engineering Design,* 15(6), 563-580, 2004. DOI:10.1080/09544820410001731128

[4] **Burgess SC**, Ling CS, Pyper T, A linear actuated chain test rig capable of accelerated test speeds, *Proceedings of the Institution of Mechanical Engineers Part C, Journal of Mechanical Engineering Science* 227(5), 1047-1055, 2013. DOI:10.1177/0954406212451546

[5] Wragge-Morley R, **Burgess S, Yon J,** A novel pendulum test for measuring roller chain efficiency, *Measurement Science and Technology*, 29(7), 075008, 2018. DOI:10.1088/1361-6501/aaa239

[6] Lodge C, **Burgess SC.** (2002) Experimental measurement of roller chain transmission efficiency, Proceedings of the International Conference on Gearing, Transmissions, and Mechanical Systems, pp.603–612.

Awards:

[a] Institution of Mechanical Engineers, 2019 James Clayton Prize

Research funding:

[i] **Burgess SC,** Project Velocity – Chain drive research, Renold Chain, 2014-2021, GBP222,500

4. Details of the impact

The roller chains developed from the research are now being used in more than 90 countries, helping to achieve high efficiency power transmission in a wide range of industries. The successful application to world-class cycling competitions has provided excellent marketing and public engagement opportunities. The technology has been showcased to over 21,000 people in physical settings and to many more through TV, radio and online. Public engagement activities have illustrated how new technology can help the environment as well as showing the excitement of careers in engineering.

Improved industrial chains

The insights gained from efficiency and wear modelling carried out at Bristol University have helped Renold refine the design of their 0.5-inch and 0.375-inch pitch roller chains. In particular, a highly optimised design of the 0.5-inch chain led by Bristol University was adopted by Renold in 2016. In addition, a highly optimised design of the 0.375-inch pitch chain led by Bristol University was adopted in 2017. The 0.5-inch and 0.375-inch pitch chain sizes are supplied to Renold Chain's customers in over 90 different countries for a wide range of industries including pharmaceutical, food, manufacturing and transport. [text removed for publication] [A].

The improved chains have had a significant impact on reducing energy consumption in industry, due to the chains' 50% reduction of power loss. The typical transmission efficiency of the new chains is 98%, up from 96%, making for an improvement of 2% of the gross power. [text removed for publication]. For a standard 15,000 hour chain life and power rating of 0.5 GW, the corresponding 2% energy saving amounts to 150 GWh of energy.

New chain test rigs for industry

In March 2020 Renold-Jeffrey (a subsidiary of Renold in the USA) commissioned a new industrial test rig based on the pendulum test rig developed at Bristol University [6] [B]. The company have said that: "*The new rig concept makes it commercially feasible for the very first time to test large industrial chains (from 2 inch to 7-inch pitch) with loads up to 9 tonnes* (Figure 2). *The new test rig is enabling the optimisation and verification of large chains which are used in heavy machinery. The optimisation particularly helps to avoid over-sizing of chains, and this enables very substantial savings in energy consumption to be made*."

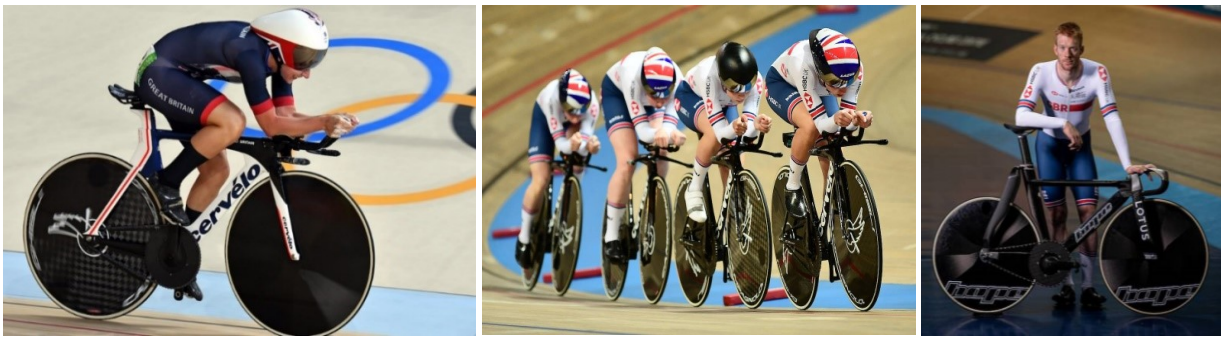
The Vice President of Renold Jeffrey went on to state: "[text removed for publication]. *Therefore, the new testing technology will have a very significant impact on our business.*" [B].

Figure 2. Large industrial drive chain, typically used for heavy construction and mining equipment (4 inch pitch and 4.5 tonne working load)

New chains for Olympic cycling

At the 2016 Rio Olympics, Team GB cycling adopted the new Renold 1/2 inch pitch chain for all track cycling events [C] (Fig. 3(a)). In addition, much larger chainwheels, designed by Bristol University, were used [3]. This was the first time that larger diameter chainwheels have been used in elite cycling.

At Rio, Team GB cycling won a record of six gold, four silver and one bronze medal and also broke two world records. One of the leaders of Team GB cycling has stated: *"The performance of the Team GB track cyclists at the Rio Olympics was outstanding and we have no doubt that the work of Bristol University was one of the many factors that contributed to this success."* [Ci]. The head of Technology at British Cycling said in a press release: "*For Rio we knew we had a gain, small, but very significant from the drivetrain…….. We knew when we were on the starting gates we had the best chain in the world*" [Cii].



(a) (b) (c)

Figure 3. The new chain technology (including larger chainwheels) on Olympic bikes: (a) Rio; (b) UCI World Championships 2019; and (c) bike for the Tokyo Olympics

The success of Team GB at Rio led to Prof Stuart Burgess being interviewed on local BBC TV a few days after the Olympics [D]. Team GB Cycling have used the new chain drive technology in at least five major championships since 2016, with the new chain sets clearly visible in television and newspaper pictures (see Figure 3).

The new 3/8 inch pitch chain subsequently developed in research since the Rio Olympics has been selected to be used at the 2021 Tokyo Olympics (Fig. 3(c)). In 2017, Renold Chain and British Cycling launched a version of the Rio Olympic chain to the club cycling market [E].

Public Engagement

The new chain drive technology [4] was exhibited at the Royal Society Summer Science Exhibition in July 2017, where there were 14,000 visitors over two weeks. A YouTube video was subsequently featured on the Royal Society website [F]. The exhibition was also shown at the Colchester Science Festival on 17 March 2018, where there were 2,000 visitors, and at the Create Centre in Bristol from June to November 2018 where it was seen by over 5,000 school children [G]. In total, over 13,000 school children and 8,000 adults attended exhibitions of the new technology and many more viewed the national coverage of the research.

The research has led to improved public attraction to engineering and cycling. At the Royal Society Summer Science Exhibition in 2017 an electronically recorded survey was carried out amongst visitors with a response return of 552 adults and 765 school children. 28% of adults said that they would definitely consider increasing the amount of cycling they do as a result of seeing the exhibition. 89% of school children said the exhibition improved their understanding of engineering.

The chain technology was also selected by the Institute of Mathematics and Applications (IMA) for a Maths Inside project to encourage school leavers to consider mathematics as a career [H] and a case study was placed on their website [H].

Several other major outreach activities have been carried out, including:

- Selected for a STEM case study by STEM.org.uk and put on their website [I]
- Featured on BBC national breakfast TV, 11 July 2017
- Featured on BBC Radio 5 & ABC Australia, The Naked Scientist, 1 August 2017

5. Sources to corroborate the impact

[A] Renold Plc (UK) (2019). Corroborating Statement, CEO

[B] Renold Jeffrey (USA) (2020). Corroborating Statement, Vice President

[C] i) British Cycling (2020). Corroborating Statement, Commercial & Technical Manager
ii) British Cycling (2018). Video: Renold announced as official chain supplier for the Great Britain Cycling Team, [accessed 10 December 2020] (*University of Bristol mentioned at 0.30min*).

[D] BBC Points West (2016). News: Bristol University team helped give Team GB the edge, [accessed 23 Sept 2020]

[E] Reynold (2017). Renold Velo CT Cycle Chain, [accessed 8 June 2020]

[F] YouTube (2017). Engineering cycling gold, [accessed 4 August 2020]

[G] Bristol City Council (2018). Corroborating Statement, Senior Create Officer

[H] Maths Careers. (2019). Engineering cycling gold, [accessed 20 May 2020]

[I] STEM Learning. Engineering success: cycling the way to Olympic Gold, [accessed 20 May 2020]

[J] The Naked Scientist (2017). The science of faster bicycles, [accessed 20 May 2020]