Institution: Newcastle University

Unit of Assessment:12

Title of case study: Sensorless control of high efficiency drives for consumer appliances

Period when the underpinning research was undertaken: 2000-present

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:**
Barrie Mecrow	Professor	1987-present

Period when the claimed impact occurred: 2013-present

Is this case study continued from a case study submitted in 2014? Y

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

Newcastle University has a substantial background in researching novel control methods for electric motors. This case study concerns the impact that our work on sensorless control systems has had upon Dyson consumer products, mainly reduced production costs and improved ergonomic design derived from the ability to eliminate bulky sensor components and separate control electronics from the motor. The technology is utilised within Dyson's Supersonic hair dryer (the technology has previously been used in Dyson vacuum cleaners) with a retail value of around £1.5Bn.

Newcastle's revolutionary research to achieve sensorless motor position enabled a way to significantly reduce cost and improve performance of position control by eliminating the mechanical sensor. The sensor-less designs will yield annual production cost savings of approximately £7-10 million.

2. Underpinning research (indicative maximum 500 words)

Newcastle University is home to one of the world's leading Electrical Power groups with a long history going back almost 100 years. Our interests in the specific topic of sensorless control originated in the research of Prof P Acarnley who identified a novel method of determining motor position, based upon the use of motor terminal voltages and line currents to estimate winding flux linkages and thus predict motor position. Acarnley continued to be a major contributor to the development of various sensorless control methods ([**R2**] and [**G4**]) and his work was further supplemented by Atkinson, Jack and Mecrow [**R1**] who applied sensorless position estimation and control methods to fault tolerant drives.

Newcastle research in this area is particularly relevant to the design of consumer products, such as hair dryers, which provide greatest efficiency and minimum mass when operating at high speeds. Almost all consumer products use brushed motors because of the high cost of power electronics and control for brushless alternatives. This has resulted in inefficient systems, with maximum speed typically limited to less than 40,000 revs/min by the brushgear. Newcastle has been working to overcome this by researching and implementing low-cost brushless drives operating at speeds of 100,000 revs/min or greater [**R3**], enabling them to be both smaller and more efficient. The research areas have included new motor topologies, use of new materials, new drive topologies and novel control schemes.

A key research project, part funded by Dyson, investigated low cost sensorless schemes for ultra-high speed drives. The research built on Newcastle's expertise in sensorless control

schemes to develop a controller for single phase drives of the type used by Dyson. Single phase drives pose particular problems. Unlike three- phase drives, the single-phase winding is always active, which immediately rules out most existing sensorless schemes. Two low cost sensorless schemes were developed: the first is used during current control mode and determines the rotor position from analysis of the active waveforms in the phase windings; the second is used in voltage control mode and indirectly determines the rotor position by estimation of the winding induced voltage via some low-cost hardware. When used together the schemes operate across all loads and the entire speed range – from standstill to over 110,000 rev/min. This research has resulted in two patent applications [**E1**, **E2**].

The Electrical Power group research in this area in the period 1993-date has attracted over one million pounds of Dyson direct funding [**G1**, **G2**, **G3**] in addition to ESPRC support in the form of individual, platform grants and now a Prosperity Partnership [**G4**, **G5, G6**].

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

Publications

[**R1**] Green, S,Atkinson, D.J., Jack, A.G., Mecrow, B.C. "Sensorless operation of a fault tolerant PM drive." IEE Proc. Electric Power Applications 150 (2) pp117-125 Mar 2003. DOI: 10.1049/ip-epa:20030153. *This extends the NCL concepts that enable a new way to achieve sensorless motor position control to a broader range of applications (specifically aerospace).*

[**R2**] Acarnley, P.P. and Watson, J.F. "Review of position-sensorless operation of brushless permanent magnet machines." IEEE Trans Industrial Electronics 53 (2) pp 252-262 April 2006. DOI: 10.1109/TIE.2006.870868

[**R3**] Bateman, C.J. Mecrow, B.C., Clothier, A.C., Acarnley, P.P.,Tuftnell, N.D. " Sensorless operation of an ultra-high-speed switched reluctance machine." IEEE Trans on Industry Applications, 46 (6), art. no. 5559420, pp. 2329-2337, 2010. DOI: 10.1109/TIA.2010.2070471 *This paper is the link between the original thread of work and the specific implementation of this class of sensor to consumer products – it focuses on a low cost and robust implementation of Sensorless control of the type required for consumer device implementation.*

Patents

[**A**] Patent Application GB1203911.1 and GB1203913.7: Sensorless Control of a Brushless Permanent-Magnet Motor.

[**B**] Patent Application GB1210371.9 and GB1210372.7: Method of Determining the Rotor Position of a Permanent-Magnet Motor.

Funding

[**G1**] Dyson Technology Centre Funding, Value £169,000, 2007-13.

[**G2**] Dyson Industrial PhD sponsorship (4 Students), Principal Investigator B.C.Mecrow, Value £252,000, 2007-2013.

[**G3**] Dyson Engineering Doctorate Research project, Principal Investigator B.C.Mecrow, Value £80,000, 2005-2009

[**G4**] EPSRC Grant GR/J07129/01 "Position estimation in rotor-position switched electric drives." Principal Investigator P. Acarnley, Value £137,061 May 1993 – Nov 1996.

[**G5**] EPSRC Platform Grant EP/F067895/1 "High Efficiency Electrical Energy Conversion" Principal Investigator B. C. Mecrow, Value £762,626, Feb 2009 – Jan 2014.

[**G6**] EPSRC Prosperity Partnership EP/T005548/1 "Dyson Future Power Systems lab", Principal Investigator B.C. Mecrow, Value £2,359,497, Sept 2020-Sept 2025, with matched funding from Dyson and Newcastle University.

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

Newcastle University's Electrical Power group has a substantial history of research collaborations with manufacturers of consumer products, including Black and Decker and LG. The group has had a fruitful research relationship with Dyson spanning 15 years. Dyson have incorporated many of the group's innovations into their products and their use of a specific, novel sensorless control scheme is the topic of this case study. Because of the need to protect commercially sensitive intellectual property the Dyson information contained here is necessarily limited. Key elements of the sensorless control work were subject to April 2012 patent applications [**E1**, **E2**] which have yet to come into the public domain.

Dyson decided to implement the sensorless control system in their hair dryer because the design offered the following benefits [E4]:

- Lower manufacturing costs and improved sales margins, "*The sensor-less designs will yield annual production cost savings of approximately £7-10 million"*
- Ergonomic benefits of flexibility and simplicity in product realisation, particularly in small machines, because there is no longer any need to incorporate a position sensor.
- Reduced complexity in the production line, leading to increased production rates and reduced costs.
- Less variation in performance within a production run and across the entire population of drive systems manufactured.
- Reduced weight of final product

Through the elimination of the position sensor the sensorless design allows for the control electronics and motor to be separated, allowing for ergonomic flexibility in designing the product's external envelope. Dyson is noted for the ergonomic design of its machines and the new control system contributes to cost savings by allowing reductions in component count and assembly complexity. Dyson say the V9 motor used within the hairdryers is *"uniquely positioned in the handle,[and] the 27mm Dyson digital motor spins, on average, 6 times faster than other hair dryer motors with one inaudible frequency – yet is a third of the weight"* [E3]. Integration of the motor in this manner is greatly eased by the sensorless system.

Dyson's Senior Director of Technology makes clear the exclusive and fundamental nature of his Company's relationship with Newcastle University in this field and the scale of products impacted by that relationship, stating:

"*One highlight has been the patented sensor-less control technology that has been implemented in our personal care products, with a retail value of about £1.5Bn. The technology has been further developed at Dyson into a second-generation version and integrated into more motor types for our stick vacuum cleaners. This will reach the market later this year in some products but will then roll out into next generation designs over the next 2- 3years.It is anticipated that annual sales of these machines will then rise to approximately 15-20 million units per annum, with a retail sales value of £5-8Bn. The sensor-less designs will yield annual production cost savings of approximately £7-10 million. On a more general note, the Company has benefited from its relationship with Newcastle University via the transfer of ideas and realisations as well as the transfer of personnel. We collaborate exclusively with Prof Mecrow's group in this field and the core of our Motors and Power Systems team continues to be recruited from within the Newcastle research group*." [**E4**]

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

[E1] Patent Application GB1203911.1 and GB1203913.7: Sensorless Control of a Brushless Permanent-Magnet Motor.

[E2] Patent Application GB1210371.9 and GB1210372.7: Method of Determining the Rotor Position of a Permanent-Magnet Motor.

[E3] Dyson Supersonic Hair Dryer [PDF of webpage] detailing research within Dyson technology

[E4] Senior Director of Technology, Dyson Ltd. Testimonial letter outlining research work. and financial benefits.