Institution: University of Sheffield

Unit of Assessment: 12A - Aeronautical, Mechanical, Chemical and Manufacturing Engineering: **Mechanical Engineering and Advanced Manufacturing**

Title of case study: Reduced production costs for aero-engine discs leads to new manufacturing facilities.

1. Summary of the impact

Aero-engine discs are complex to manufacture due to the exotic alloys required to withstand stress and temperature. Researchers at the Advanced Manufacturing Research Centre (AMRC) have devised a methodology for optimising the machining of the discs leading to a [*text removed for publication*] reduction in production time and [*text removed for publication*]. The availability of these methods has had a direct impact on the business case for a new Rolls-Royce factory in Gateshead, contributing to their decision to invest. [*Text removed for publication*]

2. Underpinning research

Aero-engine discs are at the heart of the modern jet engine. They hold the turbine or fan blades in place, and operate under extremes of stress and temperature. Consequently, they require exotic materials such as titanium and nickel super alloys.

Machining of titanium and nickel super alloy discs is traditionally constrained by tool wear, residual stress distortion and tool and part vibration. This leads to a complex manufacturing process: multiple operations are employed to correct the distortion from residual stresses, and a variety of fixtures are needed to provide maximum static and dynamic stiffness to the machining of key features.

In our approach, finite element models of the residual stress profile were used to guide the fixture design and machining strategy, so that bulk stresses could be removed and the consequent distortion could be corrected for within the same operation. This requires fixtures with open access to features, which provide less static or dynamic support.

Consequently, the research challenge is how to machine the exotic materials when the dynamic support provided by the fixture is substantially reduced. Breakthrough research at the University of Sheffield addressed this via two related streams of work: *process damping*, and *variable helix tools.*

Process damping. When machining under certain conditions, the vibration of the system is limited by the phenomenon known as process damping, which is associated with rubbing between the tool flank and the just-cut workpiece surface. Process damping is particularly relevant for difficult-to-machine metals (such as titanium and superalloys), which require lower machining surface speeds. In reference [R1] the phenomenon was extensively researched (partly funded by an EPSRC project EP/D052696/1, 2006-2010), and the relationship between vibration and machining feed rate was explored using numerical models and experimental tests. This new understanding enabled us to correctly choose the feed rate under process damped conditions. In reference [R2], the influence of tool geometry was explored using extensive experimental testing. This enabled us to understand how the tool edge geometry influenced the vibration, and consequently the productivity. As a result of this research, we were able to choose optimal machining parameters by properly exploiting the process damping phenomenon in the machining of titanium and nickel super alloy discs.

Variable helix cutting tools. Variable pitch and variable helix cutting tools have been understood to reduce vibration during milling operations. Such tools are particularly useful when machining titanium and nickel superalloys where high spindle speed stability regions cannot be exploited. Research undertaken by Turner [R3] and continued by Sims as part of his EPSRC Advanced Research Fellowship (GR/S49841/01) [R4, R5] produced models that can be used to guide optimum tool geometry for stability and the selection of cutting parameters. This research was shared with AMRC cutting tool partners Technicut who provided tooling for the milling of holes and slots on thin walled titanium and nickel discs at high productivity without unstable chatter vibration.

Summary of staff involved

All of the staff involved were based in the submitting unit at the University of Sheffield. There were two international collaborations involved in the underpinning research: Dr Mann visited Dr Sims for two months, and co-authored [R4]. Dr Mann's contribution was the validation of some of the modelling approaches. Dr Turner visited Professor Altintas's laboratory during part of his research. Dr Merdol and Professor Altintas assisted with the time-domain simulations reported in [R3].

3. References to the research

*References that best indicate the quality of the research are indicated ****

R1. *** Sims, N; Turner, S; "The influence of feed rate on process damping in milling: Modelling and experiments". *Proceedings of the Institution of Mechanical Engineers, Part B, Journal of Engineering Manufacture*, 2011, **225**: 799-810. Winner of the IMechE Joseph Whitworth Prize 2011. doi: 10.1243/09544054JEM2141

R2. Yusoff, AR; Turner, S; Taylor, CM; Sims, ND, "The role of tool geometry in process damped milling". *International Journal Of Advanced Manufacturing Technology,* 2010, **50**: 883-895. doi: 10.1007/s00170-010-2586-6

R3. *** Turner, S., Merdol, D., Altintas, Y., Ridgway, K. "Modelling of the stability of variable helix end mills", *International Journal of Machine Tools and Manufacture*, 2007, **47**:1410-1416.

R4. Sims, N. D., Mann, B., and Huyanan, S., 'Analytical prediction of chatter stability for variable pitch and variable helix milling tools'. *Journal of Sound and Vibration*, 2008, **317**: 664-686.

R5. *** Yusoff, A. & Sims, N. Optimisation of variable helix tool geometry for regenerative chatter mitigation, *International Journal of Machine Tools and Manufacture,* 2011, **51:** 133-141.

4. Details of the impact

In parallel with the underpinning research activity, Rolls-Royce (who were a partner on our EPSRC-sponsored process damping research) identified a need for a new disc production facility in order to meet the demand for new engine platforms. The role of the AMRC's research is explained by Rolls-Royce [S1] as follows:

[*Text removed for publication*]

For each example disc, the underpinning knowledge concerning process damping and special tool geometry was implemented to achieve vibration free and high productivity machining of the titanium or nickel alloy component. This increased resistance to vibration meant that more flexible fixture configurations could be used, further reducing the cycle time for each component.

Other research activity also supported the resulting business case [*Text removed for publication*], but the research undertaken in the unit (Section 2), and the subsequent technology development programme at the AMRC (above) is cited by Rolls-Royce [S1] as one of the important factors.

[*Text Removed for publication*]

The new factory also will have a tangible societal impact on the local community, since the new production facility will regenerate the former Dunlop Tyres site, which was closed in 2006 with the loss of 585 jobs [S7].

More broadly, the research has had a secondary impact by informing public policy and contributing to parliamentary debate concerning the development of the UK's Catapult Centres [S8].

5. Sources to corroborate the impact

S1. Letter from Rolls-Royce corroborates the economic impact on Rolls-Royce as cited directly in Section 4.

S2. "Rolls-Royce breaks ground for new facility in North East". Rolls-Royce Press Release, 21

September 2012. (on file). This Rolls-Royce press release corroborates the size of the new factory (20000m^2), and the role of the AMRC in the underpinning research.

S3. “400 jobs saved as plant Rolls-Royce moves eight miles”, The Journal, 11 February 2010 (on file). This newspaper article corroborates the estimated 400 jobs safeguarded.

S4. “A total of £45m funding to Rolls-Royce which will see them build a total of four new manufacturing facilities creating and sustaining around 800 jobs…”, in “Advanced Manufacturing Package”, Department for Business, Innovation and Skills. First published July 2009. Crown Copyright. BIS/07/09/NP. URN 09/1116. Page 17 (on file). This corroborates the public funding support for the factory.

S5. 20,000 m^2 factory, at £1,556 / m^2, giving £31 Million. Cost per square meter based upon building cost estimates in 2011, for a ‘high-tech factory/laboratory’: International construction cost survey 2012, Turner & Townsend (page 35, on file). This estimates the value of a 20,000 m^2 factory.

S6. “The construction contract, thought to be worth £35m…”, in “Miller to build new Rolls-Royce factory”, *Building*, 25 September 2012. (on file). This estimates the value of a 20,000 m^2 factory.

S7. “Dunlop closure to cost 585 jobs”, Daily Telegraph, 6 April 2006. (on file). This newspaper article corroborates the societal regeneration associated with the redevelopment of the Dunlop site.

S8. “Recent work on disk machining with Rolls-Royce (and funded by TSB) has justified the construction of a new disk manufacturing facility in Sunderland”, in “Written evidence submitted by Advanced Manufacturing Research Centre (AMRC), University of Sheffield (TIC 35)”, UK Parliament Science and Technology Committee, Technology and Innovation Centres. (on file). This corroborates the secondary impact that has occurred by informing parliamentary debate.