UTS Contract Research Grant

UTS PRO18-6590/ALS 61306

An investigation into the industrial application of laser Doppler vibrometry

Final Report

Prepared by:
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F.A.O. Gerrie Visser, ALS Industrial, Riverview, QLD.

Sept 2019

OVERVIEW

This research project was conceived and developed through communication between Dr Ben Halkon and Mr Ian Cheong, formerly of ALS Industrial, in response to a client crankshaft torsional vibration issue which was leading to premature challenges. The application of rotational laser vibrometry to directly determine the torsional damper vibration levels, in combination with other, traditional sensor techniques was agreed.

With reference to the Research Services Agreement in Appendix 1, the role of Dr Ben Halkon was to offer access to the required laser vibrometry equipment and associated accessories, consult on the successful application of the equipment to the industrial measurement campaign, to support with the interpretation of the measured data and with the preparation of the final report.

Initially the project was proposed for the interrogation of a single system. Subsequently, the project was varied to include the interrogation of a second, similar system. This Final Report simply provides a high-level overview of the undertaking of the project, including the key dates and activities and some of the main observations and findings. The specific detail relating to the findings of the project can be found in the ALS Industrial Confidential document that was prepared, submitted and accepted by the client and is entitled: "Report No: 061306-Rev0 Torsional Vibration, Package Vibration and Operational Deflection Shape Measurements on Waukesha Engines Frick Screw Compressor Packages"; refer to Appendix 2 for the front cover.

SUMMARY OF PROJECT OUTCOMES

The project has developed the following:

- Ian Cheong visit, 3rd Oct 2018, to UTS for 1 day bespoke, personalised training on the effective application of laser Doppler vibrometry to industrial rotating machinery measurements;
- Consultancy with the development of the client-facing ALS proposal to incorporate the LDV measurements into a large-scale measurement campaign and development of test engineer protocols for the successful set-up of the equipment and measurement acquisition;
- Mobilisation of equipment for first field-based measurement campaign on 9th Oct, 2018 for receipt confirmed on 11th Oct, 2018 – testing on 16th Oct 2018;
- Consultancy with data interpretation and initial findings during period 15th Oct thro' 1st Nov, 2019;
- Variation to project agreement to enable second period of testing and consultancy;
- Mobilisation of equipment for second field-based measurement campaign on 8th Nov, 2018;
- Return of all equipment in full working order to UTS on 15th Nov, 2018;
- Consultancy with data interpretation and initial findings during period Nov thro' Dec, 19;
- Consultancy with report completion during period Jan thro' Mar, '19;

- Ben Halkon visit, 15th Feb 2019, to ALS Industrial for 1 day to participate in monthly countrywide meeting (hosted by Pete Caldwell) and present on "Some Fundamentals and Practical Applications of Laser Doppler Vibrometry";
- Finalisation of report to client on 8th March 2019;
- Introduction of final year Mechanical Engineering student, Hugh Carwardine, to Gerrie Visser and follow-up interview visit by Hugh to Riverview in Sept 2019.

Please refer to Appendix 3 for a summary of the primary initial observations and findings from an industrial application of rotational laser vibrometry standpoint, i.e. per the project described here.

CONCLUSIONS

The project was completed successfully and in line with expectations. Bespoke face-to-face training was completed at UTS with equipment supplied to ALS for field-based testing during late Oct and early Nov 2018. Consultancy was completed with preparation of the test methodology, interpretation and presentation of the results and preparation of the final report. Furthermore, participation in a review meeting was completed with a presentation on other possibilities for the application of laser vibrometry given. It is hoped that there will be further projects with ALS as the need arises in the future.

APPENDIX 1 - FINAL RESEARCH AGREEMENT

UTS

RESEARCH SERVICES AGREEMENT

Terms Sheet		
Parties	**University of Technology Sydney** (ABN 77 257 686 961) of 15-73 Broadway, Ultimo, NSW, 2007 **("UTS")** and **ALS Industrial Pty Ltd** (ABN 21 006 353 046), of 299 Coronation Drive, Milton QLD 4064 **("You, Your")**	
Project	A study into the industrial application of laser Doppler vibrometry	
Term	Start date: 8/10/2018 End date: 14/10/2018	
Deliverables & Milestones	As specified in the Schedule.	
Fees (excl GST)	Total: $9,000 $ 4,500 on 5 November 2018. $ 4,500 on acceptance of the final report Each payment is subject to receipt of a valid tax invoice	
UTS Lead/Faculty	Dr Benjamin Halkon 02 9514 9442 Benjamin.Halkon@uts.edu.au	
Addresses for Service:	**For UTS** Director, Research & Innovation Office University of Technology Sydney PO Box 123, Broadway NSW 2007 Tel: (02) 9514 9681 Fax: (02) 9514 1244 Email: rio@uts.edu.au	**For You** Ian Cheong Mechanical & Materials Enginner, Industrial 7 Brisbane Rd, Riverview QLD 4303 (07) 3816 5574 ian.cheong@alsglobal.com
Attachments	☒ General Terms and Conditions ☒ Project Proposal/Milestones and Deliverables (Schedule)	

1

Ethics/Biosafety Required?	Not Applicable

Agreement

This Agreement consists of this Terms Sheet, the General Terms and Conditions and the attached Schedule.

Priority

If a conflict arises between the terms and conditions of this Agreement, the following order of priority will apply:

(a) Terms Sheet
(b) Schedule
(c) General Terms and Conditions

By executing this Agreement each signatory represents that he or she is authorised to sign on behalf of their entity.

SIGNED for and on behalf of THE UNIVERSITY OF TECHNOLOGY SYDNEY by its duly authorised representative:

....
Signature

....
Name of signatory

....
Position

Date: ....

SIGNED for and on behalf of ALS Industrial Pty Ltd by its duly authorised representative:

[signature]
Signature

JULIAN VAN DER KLEY
Name of signatory

BUSINESS MANAGER
Position

Date: 26/10/18

Date: The date of this Agreement is the last date on which the Agreement has been signed by all parties.

APPENDIX 2 – ALS INDUSTRIAL REPORT 061306 FRONT SHEET – FINAL UTS VERSION

ALS Industrial Pty Ltd
7 Brisbane Road
Riverview QLD Australia 4303
T +61 7 3816 5500 F +61 7 3282 0118
ABN: 21 006 353 046

Client: QGC PTY LIMITED

Attention: **David Flannagan / Arne Van Der Kruk**

Your Reference: CTR-036

Date: 08/03/2019

Report No: 061306-Rev0

Torsional Vibration, Package Vibration and Operational Deflection Shape Measurements on Waukesha Engines Frick Screw Compressor Packages

Prepared by
Ian Cheong
Mechanical Engineer

Reviewed By
Gerrie Visser
Engineering Manager

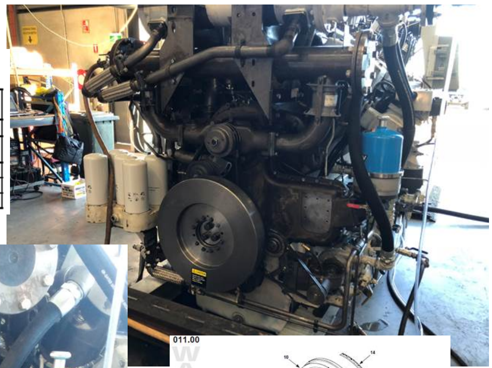
LDV Methodology and Results Reviewed By
Dr Ben Halkon
Senior Lecturer, Centre for Audio, Acoustics and Vibration, University Technology Sydney

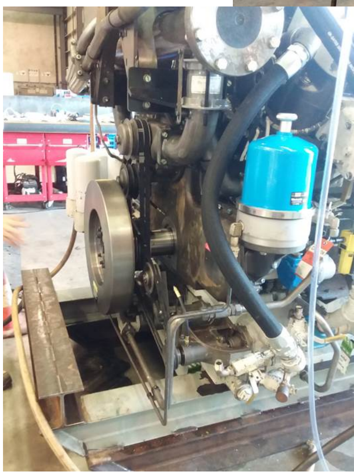
Assisting: Muhammad Fahad
Mechanical Engineer
Cameron Wilson
Senior Condition Monitoring Technician
Jack Lamont
Senior Condition Monitoring Technician

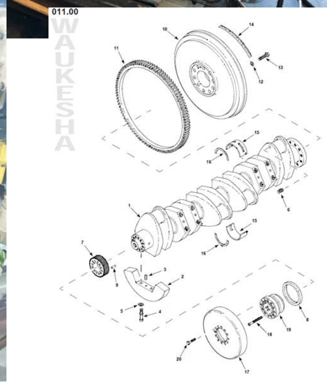
APPENDIX 3 – OVERVIEW OF PRIMARY OBSERVATIONS AND FINDINGS

Torsional vibration acceptability guidelines are specified in the table below:

DAMPER HOUSING TORSIONAL VIBRATION ACCEPTABILITY GUIDELINES, INDIVIDUAL ORDERS		
Order of Shaft Rotation	Degrees, pk-pk	
	VHP 6/12-Cyl.	All Other Engines
0.5	2.5	3.5
1.0	0.7	1.0
1.5+	0.3	0.4







The background to the project

ALS provide condition monitoring services to oil & gas exploration and extraction clients

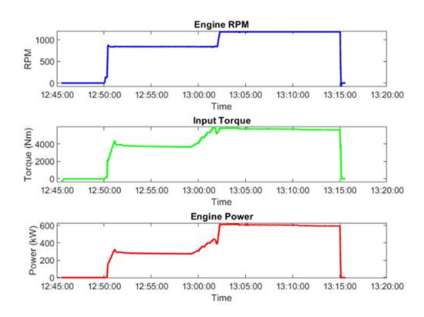
Recently the crankshaft for a V12 engine powering a gas compression stage failed due to a faulty torsional damper (17) which had not been serviced/replaced within 8-10 yrs

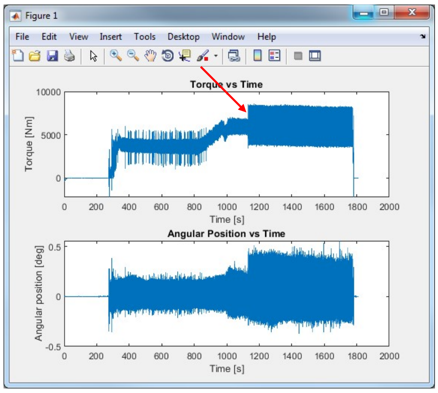
Vibration limits at the damper are specified on an order basis (see table above)

Previously the sensing technology used to determine the vibration health/signature for the engine was a series of strain gauges fitted to the crankshaft located at the flywheel end

While this can given information regarding the stress in the crankshaft at the damper end, the signals can be problematic to obtain and a crankshaft modal model is required

Preferable is to directly measure the torsional vibration at the torsional damper





Engine run-up at no load

Here the engine was run up over a period of approx. 26 mins (1600 secs)

The condition was that the engine was under no load; changes in engine RPM were rapid

The instantaneous torque presented in the second plot is derived from strain gauges on the crankshaft at the back end of the engine

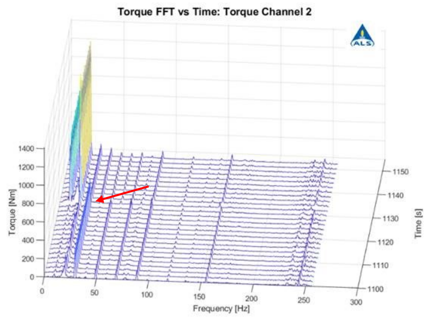
As can be seen from the vibration level 100 or so seconds into the final step, a sudden increase in vibration level occurs with very little difference in the engine performance

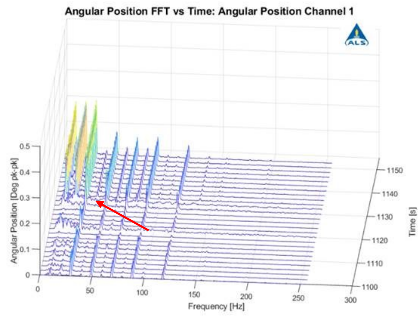
This is tricky to reconcile; further investigation is overleaf

Engine run-up at no load – order plots

Upon order processing, it can be seen that, at the point in time where the crankshaft instantaneous torque suddenly changes, the dominant orders of the vibration change from 1x and 1.5x to 0.5x and 1x

Similarly, the angular position data shows significant increase in 0.5x, 1x and 1.5x at the same moment

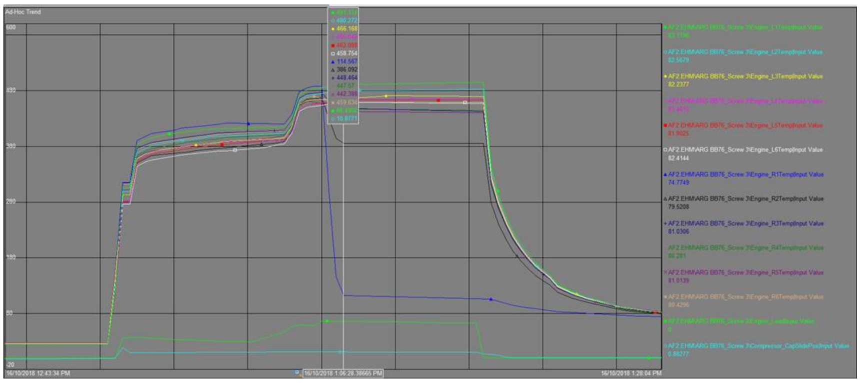




Engine misfire is the reason for the high vibration level

At exactly the same time as the vibration level increased significantly, the Engine_R1 cylinder "went cold"

This would explain the change in vibration level and order concentration



Angular position output is an integral of angular velocity 1

Unlike in many Polytec single beam translational vibrometers, where multiple decoders allow velocity and simultaneous independent displacement outputs, in the RLV, angular position is (simply) the integral of the angular velocity signal

The RPM filter function (DC, Slow, Medium, Fast) determines what proportion of the low frequency part of the total measured Doppler signal is consider RPM and what is considered to be angular velocity:

RPM filter Response	Rise time: $t_{10\text{-}90}$ [ms]	Cutoff frequency f_{max} [Hz]	RPM Readout Response time $t_{90\%}$ [s]
DC	700	0.5	2
Slow	700	0.5	2
Medium	140	2.5	0.5
Fast	28	12.5	0.5

2.2 Operating Principle

The optical measurement principle for the rotational vibrometer is based on laser interferometry. Use of the RLV is not limited to cylindrical parts. By using a special differential measurement process with two laser beams, independently of the shape of the object under investigation, only the rotational movement component is acquired and translational vibrations are predominantly suppressed.

The signal paths are displayed schematically in the following figure.

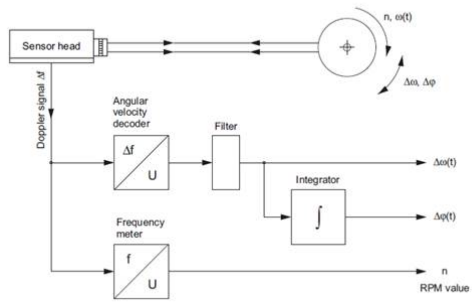


Figure 2.2: Signals in the rotational vibrometer

Angular position output is an integral of angular velocity 2

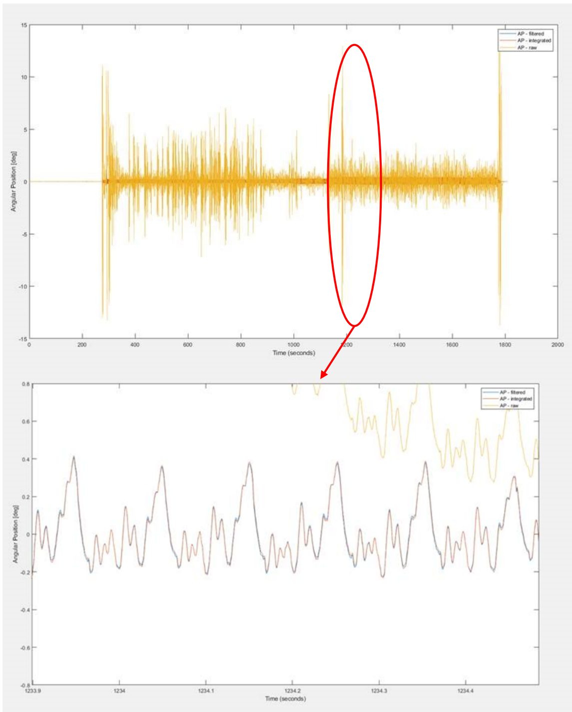
RPM filter is an important parameter to define correctly for non-steady-state testing

In this experiment, Slow setting was used

This would normally be ok for steady-state conditions but, following significant changes in engine RPM, espec. true in the unloaded condition where such changes happen rapidly, the integration algorithm takes time to settle

To check this, the “AP – raw” angular position data was bandpass filtered between 5-500 Hz

This – “AP – filtered” – is compared directly with the integral – “AP – integrated” of the angular velocity signal



Summary

- RPM filter must be selected carefully when non steady-state testing
- Integrating velocity signal might be preferable where significant RPM fluctuations occur
- Given the change in engine orders at the sudden increase in vibration, the front-running candidate has to be that this is a result of a cylinder cut/misfire