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Committee D02 on PETROLEUM PRODUCTS AND LUBRICANTS

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Originally Issued: December 3, 2015

Reply to: Richard Grundza
ASTM Test Monitoring Center
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Unapproved Minutes of the October 27, 2015
Sequence IV Surveillance Panel Meeting.

The meeting was called to order by Chairman Buscher at 9:00 AM Eastern Time.

A list of attendees is included as attachment 1.

A copy of the agenda is included as attachment 2.

Minutes from the 6/4/2015 Meeting were approved with no corrections.

Action Items from Previous Meeting
A review of the status of action items from the previous meeting was under taken. (see attachment 3)

1. Action Item – Haltermann to supply C of A data, in Excel format, for Haltermann KA24E Green fuel batches, produced from 1/1/2013 through 12/31/2015, to the ASTM TMC for posting on the TMC website. Not completed, Rich Grundza admitted he had neglected to follow up on this item and will address it in the next few days.

2. Action Item – Add Haltermann KA24E Green fuel batch C of A data into Sequence IVB test report and data dictionary. This will be addressed with other changes upon completion of the matrix.

Hardware review

There are 3 labs running tests on four to six stands and based on surveys of the labs, there are some 700 cams remaining. This translates to anywhere from a two to eight years of test life. Labs have begun to use engines and heads that were removed from service. Many of these engines and heads had additional runs on them, based on today's limits, but were removed in accordance with the number of runs given in the procedure at that time. See attachment 4.

RO 300 Intoduction

With regards to the introduction reference oil 300, the panel agreed not to introduce this oil for the IVA at the previous meeting due to random high lobe wear issues and concerns about the potential for severity shifts with this oil.

TMC Report

Rich Grundza of the Test Monitoring Center provided a quick update on severity and precision of the IVA test. Both severity and precision are in control and precision estimates for the period ending October, 2015 are comparable to historical levels. There are 3 calibrated labs with a total of 4 stands and all labs and stands are calibrated on the reground hardware. A copy of TMC report can be accessed via the following link:
ftp://ftp.astmtmc.cmu.edu/docs/gas/B01SemiAnnualReports/semiannualreports/B01%20SemiAnnualReport%20-%20Oct%202015.pdf

Scope and Objectives

The scope and objectives were reviewed and are included as attachment 5.
Driveline mounting is incomplete. The panel agreed this needs to be kept open and active and the panel needs to resolve these items regarding driveline. Labs have procedures for replacement of driveline components but further refinements and understanding of the influence on tests need to be pursued, this was left as on going.

IVB Development

Bill Buscher reviewed the work to date on the development of the IVB. The IVB Task Force is trying to deal with random high lobe wear. Failures have been noted with the SD/SE oil and on a total of eight candidate tests. There was considerable discussion on the wear phenomena noted to date. It was noted that the lobe failure occurs ~ 10% of the time and lobes are worn completely, almost to the base circle. Lobe failures can be noted in higher iron levels for all tests, but lobe failures affect AFR and engine speed control for only some tests and doesn't result in notable noise when the engine is running. A number of presentations were given regarding wear issues in the labs and two video presentations were given which are not included in these minutes. See attachments 6, 7 and 8. The video presentations showed lifter rotation and lack of lifter rotation as well as lifters rotating clockwise and counterclockwise. Discussions took place with regards to lifter rotation and its impact on wear. It was mentioned that the orientation of the spring may influence direction of lifter rotation and it was noted that flipping the spring did not seem to consistently alter the rotation orientation, i.e. clockwise or counter clockwise. Screening of lifters was also discussed and analysis of wear patterns on lifters was reviewed as well. Additional discussions also took place regarding the orientation the cam over the lifter and how it may or may not contribute to lifter rotation.

Additional items discussed pertaining to IVB development included some issues identified as the result of a wear round robin, attempting to resolve severity issues at one lab and additional items necessary to be able to start the Precision Matrix. It was noted that a revision of the engine build manual needs final review before it can be used and it is anticipated that the Precision Matrix will start in December, pending the outcome of the additional items the Task Force needs to address.

The meeting was adjourned at 12:28 PM.

A listing of action items from this meeting is included as attachment 9

MEMBERSHIP
ASTM IVA SURVEILLANCE PANEL

October 27, 2015

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Attachment 2

Sequence IV Surveillance Panel

Southfield, MI
USCAR
October 27, 2015
9:00 a.m. - 12:00 p.m.

A G E N D A

1.	Chairman comments	
2.	Attendance sign-in sheet distribution	
3.	Membership changes	
4.	Motion and action recorder	
5.	Approval of minutes for 6/4/2015	All
6.	Action item review	Chairman
7.	Status of test availability	Labs
8.	Status of test hardware	Labs
9.	Fuel supplier report – KA24E Green fuel	Haltermann
10.	TMC reports (A*ny questions?*)	TMC
11.	Review scope & objectives	Chairman
12.	Old business	
13.	New business	
14.	Sequence IVB Task Force Meeting	All
15.	Motion and action item review	
16.	Next meeting	
17.	Adjourn	

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Attachment 3

Motions and Action Items
As Recorded at the Meeting by Bill Buscher

3. Action Item – Haltermann to supply C of A data, in Excel format, for Haltermann KA24E Green fuel batches, produced from 1/1/2013 through 12/31/2015, to the ASTM TMC for posting on the TMC website.

4. Action Item – Add Haltermann KA24E Green fuel batch C of A data into Sequence IVB test report and data dictionary.

Attachment 4

Sequence IVA Estimated Availability

As of 6/1/2015

Lab	Number of Stands	Calibrated Stands	Number of Runs	Estimated Years	Limiting Factor
A1	4	2	375	5	Camshafts, or Engines if Excessive 0W-16 Testing
B1	1	1	267	8	Camshafts
F	1	1	50	2	Camshafts
Total	6	4	692	2 - 8 Year Range	Camshafts

Attachment 5

ASTM Sequence IV Surveillance Panel

Scope and Objectives

Scope

The Sequence IV Surveillance Panel is responsible for the surveillance and continued improvement of the Sequence IVA test documented in Test Method D 6891 as updated by the Information Letter system. Data on test precision and laboratory versus field correlation will be solicited and evaluated at least every six months. Improvements in wear measurement technique, test operation, test monitoring and test validation will be accomplished through continual communication with the Test Sponsor and Parts Distributor, ASTM Test Monitoring Center, ASTM Committee D02.B0.01 and the ASTM Passenger Car Engine Oil Classification Panel. Actions to improve the process will be recommended when deemed appropriate based on input from the proceeding. The Panel will review development and correlation of updated test procedures with previous test procedures. This process will provide a suitable test procedure for evaluating an automotive lubricant's effect on controlling cam lobe wear for overhead valvetrain equipped engines with sliding cam followers.

Objectives	Target Date
1. Pursue engine mounting and driveline identification, optimization and maintenance procedure and interval.	*On-going*

William A. Buscher III, Chairman
Sequence IV Surveillance Panel

Updated: Oct. 2015

Attachment c

TOYOTA

Sequence IVB Development Update

ASTM Task Force
October 27, 2015

Prepared by:
William A Buscher III

Agenda

TOYOTA

- Intake Camshaft Lobe Failure Issue
  - Details on Issue
  - Testing To-date
  - Failure Analysis
  - Other Investigations
- Wear Measurement Round Robin
- Status of Precision Matrix Labs
- Status of Precision Matrix
- Status of Test Procedure, Engine Assembly Manual, Report Forms and Data Dictionary

Intake Camshaft Lobe Failure Issue

TOYOTA

- An issue has developed in the Sequence IVB test with regards to camshaft lobe failures on the test specific intake camshaft
- About a year ago a development test, that was conducted on the poor wear test development oil, experienced two camshaft lobe failures on the intake camshaft
- At the time, it was thought to be an outlier and rare phenomena
- Over the past several months of development and candidate testing, which includes a wider variety of oils, camshaft lobe failures have occurred in a random nature on several tests
  - Some of these tests were terminated early due to a loss of AFR control, which results from the camshaft lobe failures
- In response to the increased frequency of camshaft lobe failures and the inability to run tests to completion, Toyota and the test development team agree that this issue needs to be addressed and resolved prior to starting the precision matrix

Intake Camshaft Lobe Failure Issue

- Original hardware combination: low entrainment lobe profile and medium hardness lobe surface (HV450) intake camshaft + high tension intake valve springs
  - To-date experienced ≈ 10% lobe failure rate combined, with development and candidate oil tests
  - Repeat tests conducted on multiple development and candidate oils, and lobe failures did not repeat
  - Lobe failures not believed to be oil related
  - Addressing with changes to hardware

Lab	Stand	Test Number	Oil	Viscosity Grade	Date Completed	Test Length (hours)	Intake Camshaft Batch	Time of Failure (hours)	Number of Failed Intake Lobes	Failed Lobe Position 1	Failed Lobe Position 2	Failed Lobe Position 3	Failed Lobe Position 4	Failed Lobe Position 5	Failed Lobe Position 6
Intertek	101	IVB101-0-2	SD / SE Oil	0W-20	11/6/2014	200	TEST DEV	185 - 190	2	2	8				
Intertek	102	IVB102-1-6	Candidate Oil	5W-30	2/19/2015	200	TEST DEV	185 - 190	1	3					
Intertek	102	IVB102-3-8	Candidate Oil	5W-30	3/20/2015	185.69	TEST DEV	160 - 165	2	6	7				
SwRI	18	18-0-8	Candidate Oil	0W-16	4/25/2015	200	TEST DEV	195-200	2	2	3				
SwRI	19	19-0-39	Candidate Oil	0W-16	6/20/2015	199.6	TEST DEV	195-200	6	2	3	4	5	6	7
Intertek	102	IVB102-12-17	Candidate Oil	5W-30	7/9/2015	200	OHT	195 - 200	1	1					
SwRI	19	19-0-42	Candidate Oil	5W-30	8/7/2015	191.6	TEST DEV	190-195	3	1	2	3			
SwRI	19	19-0-43	Candidate Oil	0W-20	8/27/2015	96.1	OHT	94-96	1	7					
SwRI	20	20-0-33	Candidate Oil	N/A	8/28/2015	118.3	OHT	105-110	1	7					
Intertek	101	IVB101-0-19	1006-2	5W-30	8/31/2015	147.07	OHT	140 - 145	1	7					

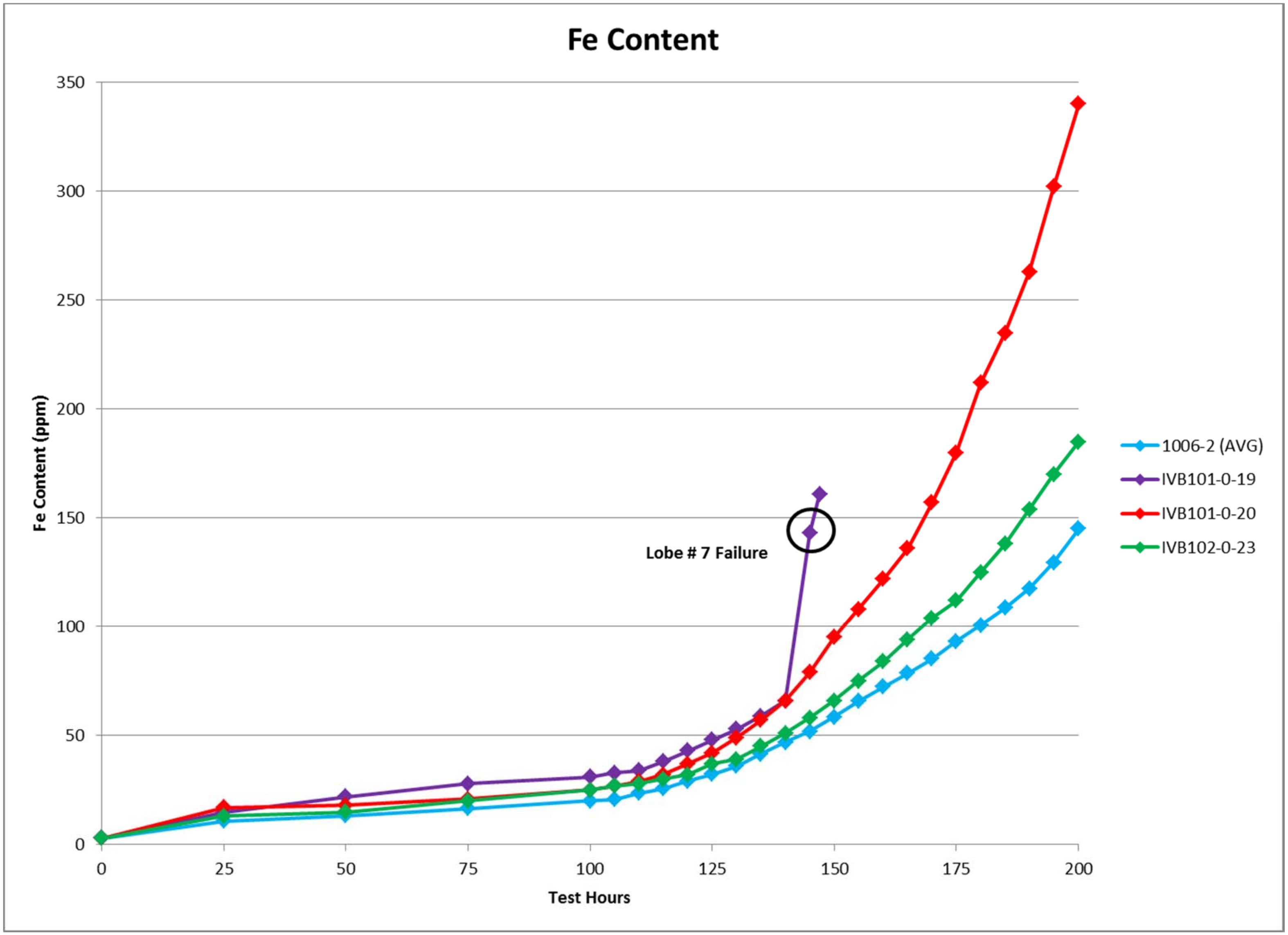
Intake Camshaft Lobe Failure Issue

TOYOTA

- First revised hardware combination: low entrainment lobe profile and **production** hardness lobe surface (**HV700 - 750**) intake camshaft + high tension intake valve springs
  - 4 development tests conducted
  - 2 tests at Intertek on stands 101 and 102 using ASTM REO 1006-2
    - Neither test experienced any intake lobe failures
    - Both ran to completion (200 hours)
    - Both produced intake lifter average area loss and average volume loss results severe of the average of the DOE matrix results
  - 1 test at Intertek on stand 101 using ASTM REO 300
    - **Test experienced one intake lobe failure (position 4) at 152.8 hours**
    - Test terminated at 153.6 hours due to loss of AFR control and engine speed control
  - 1 test at SwRI on stand 18 using ASTM REO 300
    - Test aborted at 135.7 hours due to high oil consumption
    - No intake lobe failures occurred up through 135.7 hours
  - **Conclusion = Increasing lobe surface hardness alone, will not resolve the lobe failure issue**

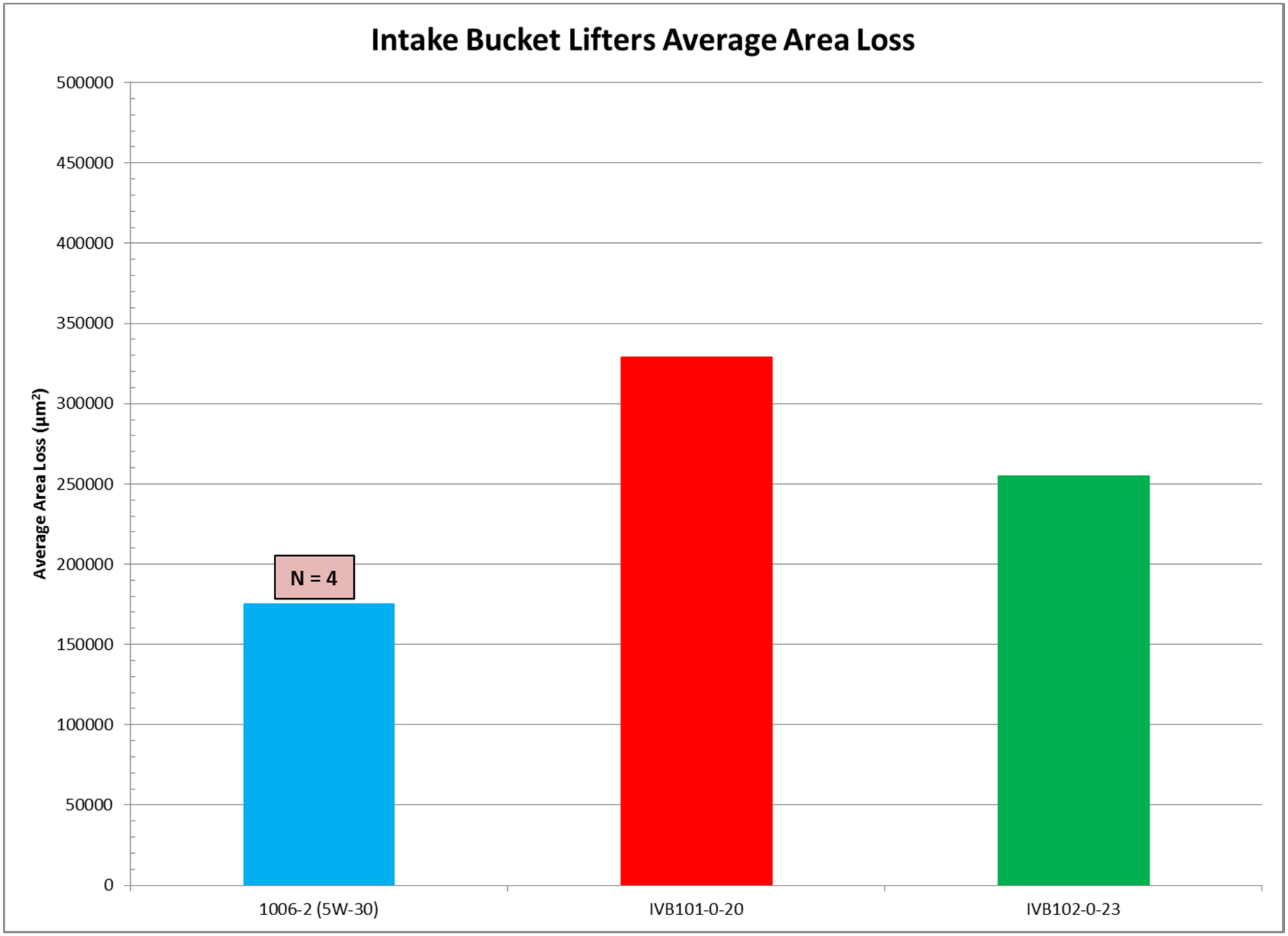
Intake Camshaft Lobe Failure Issue

TOYOTA



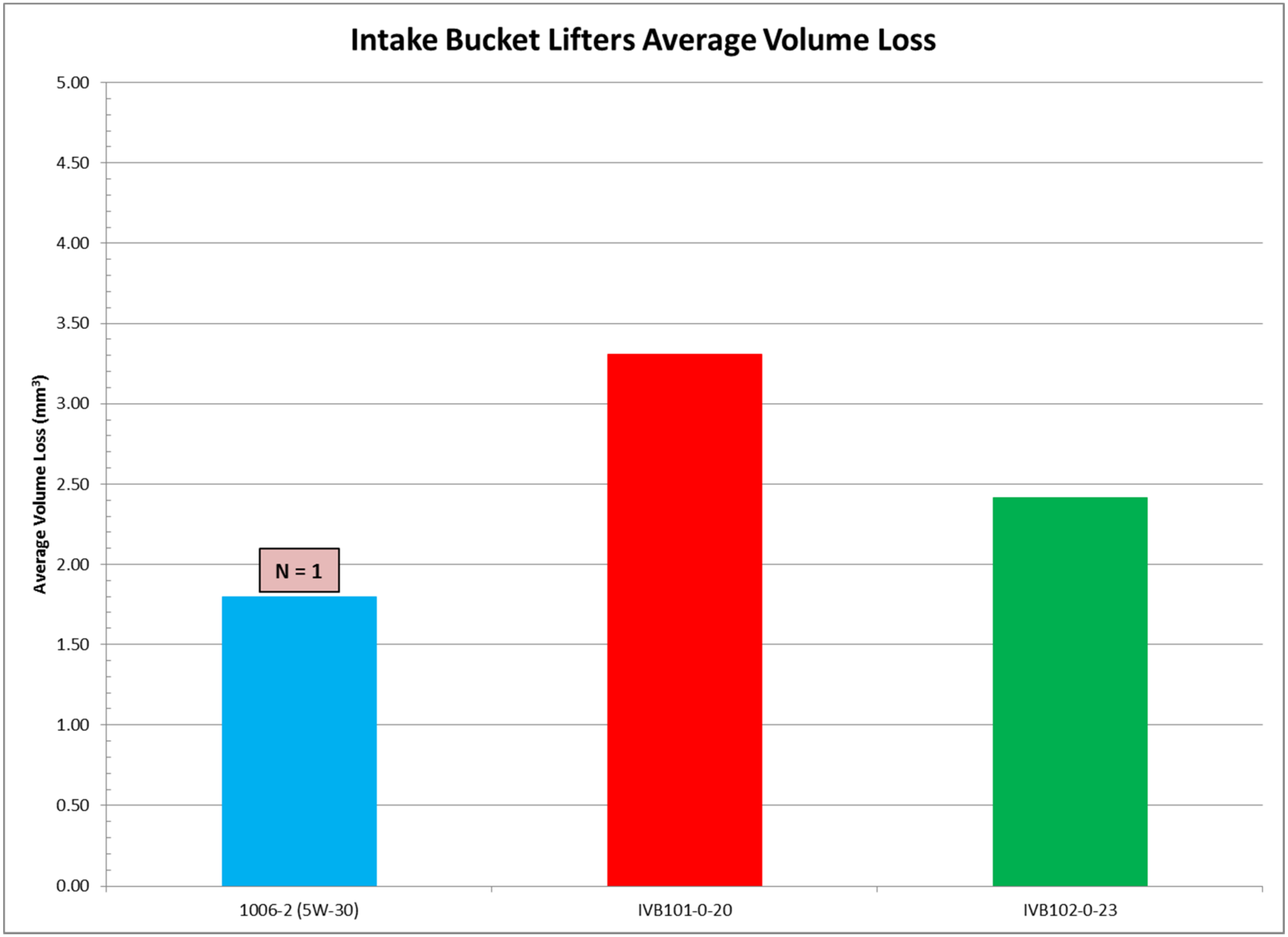
Intake Camshaft Lobe Failure Issue

TOYOTA



Intake Camshaft Lobe Failure Issue

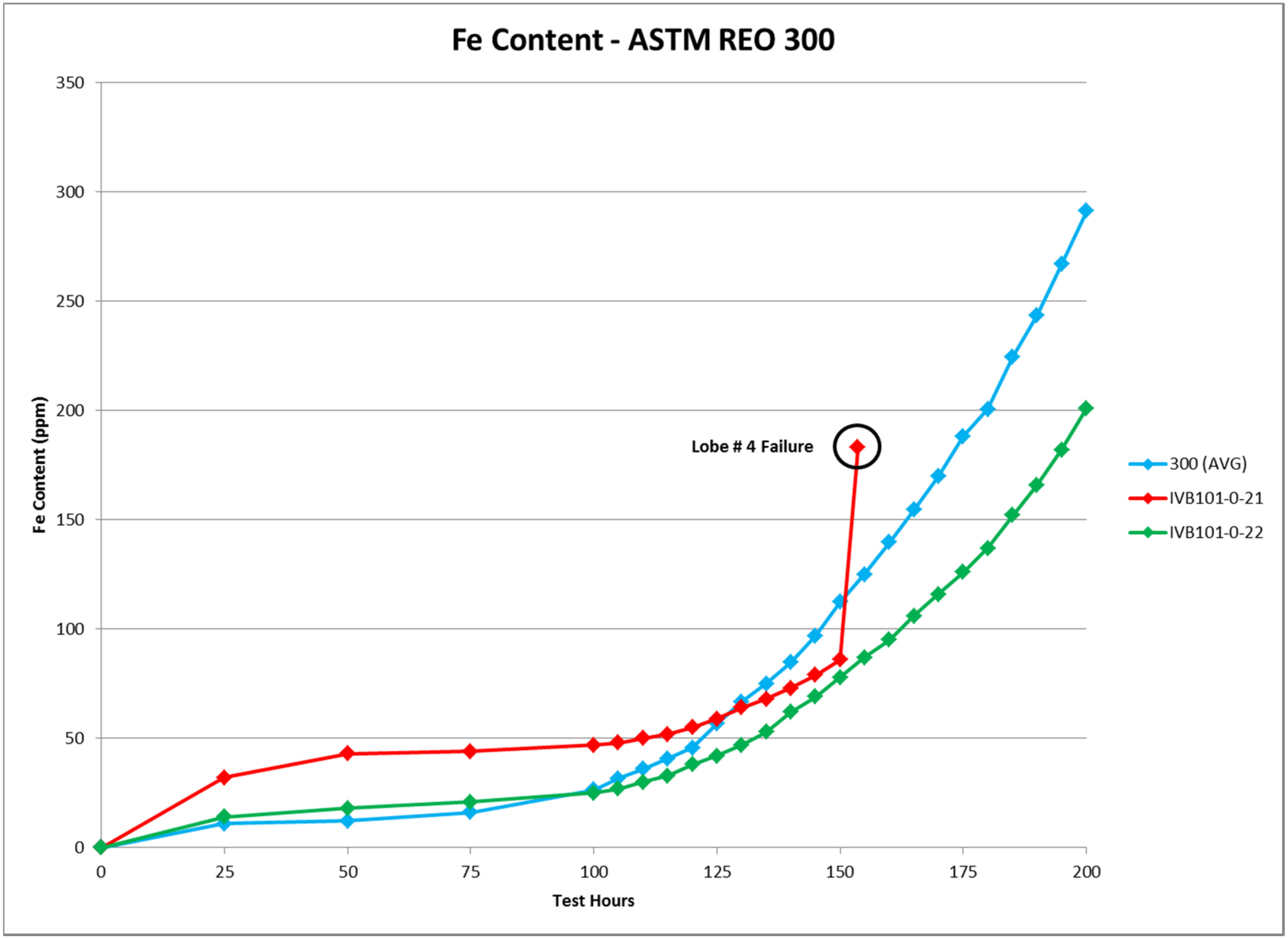
TOYOTA



- Second revised hardware combination: low entrainment lobe profile and **production** hardness lobe surface (**HV700 - 750**) intake camshaft + **production** tension intake valve springs
  - 1 development test conducted
  - 1 test at Intertek on stand 101 using ASTM REO 300
    - Test did not experience any intake lobe failures
    - Test ran to completion (200 hours)
    - Test produced intake lifter average area loss and average volume loss results mild of the average of the DOE matrix results

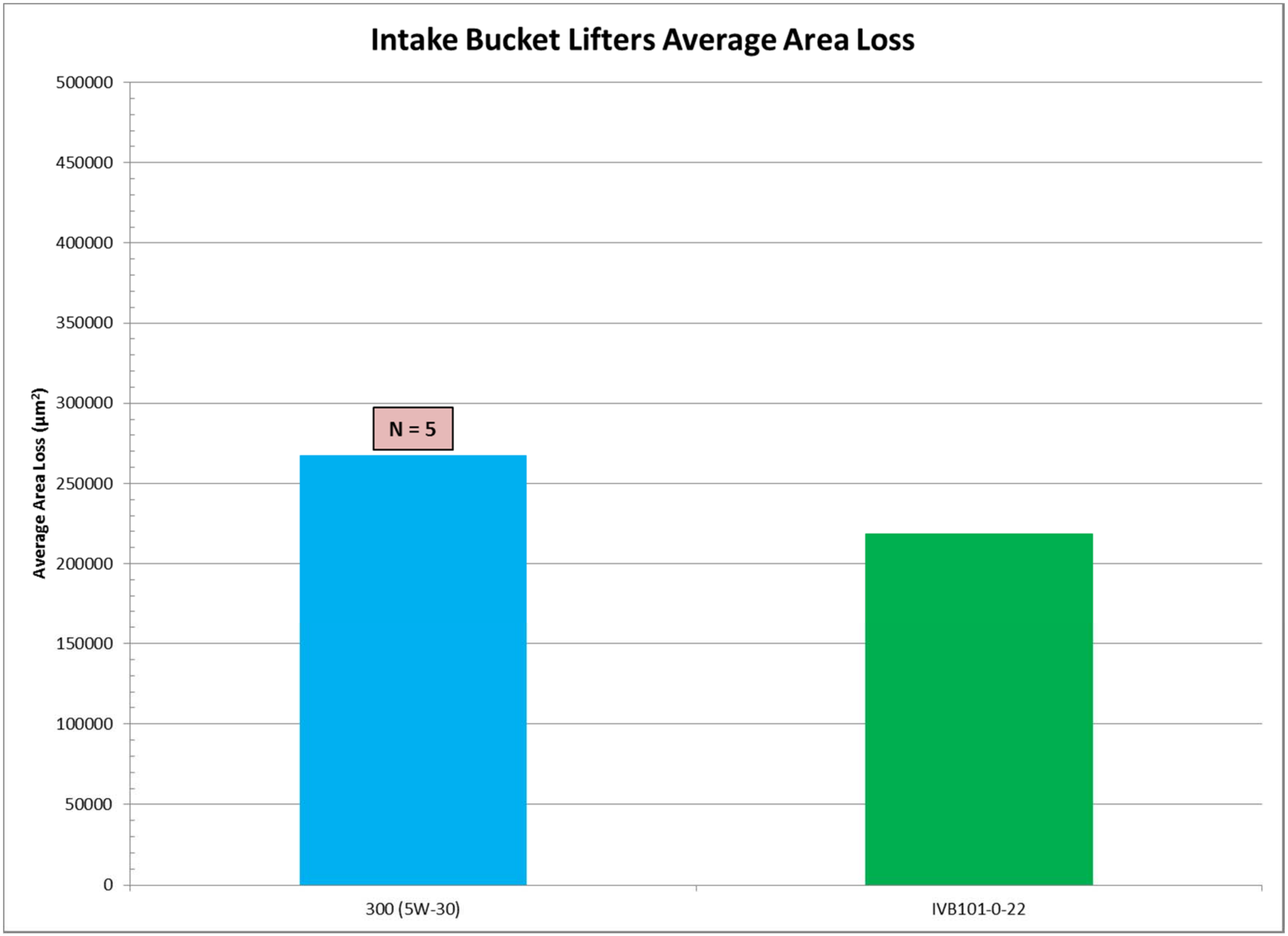
Intake Camshaft Lobe Failure Issue

TOYOTA

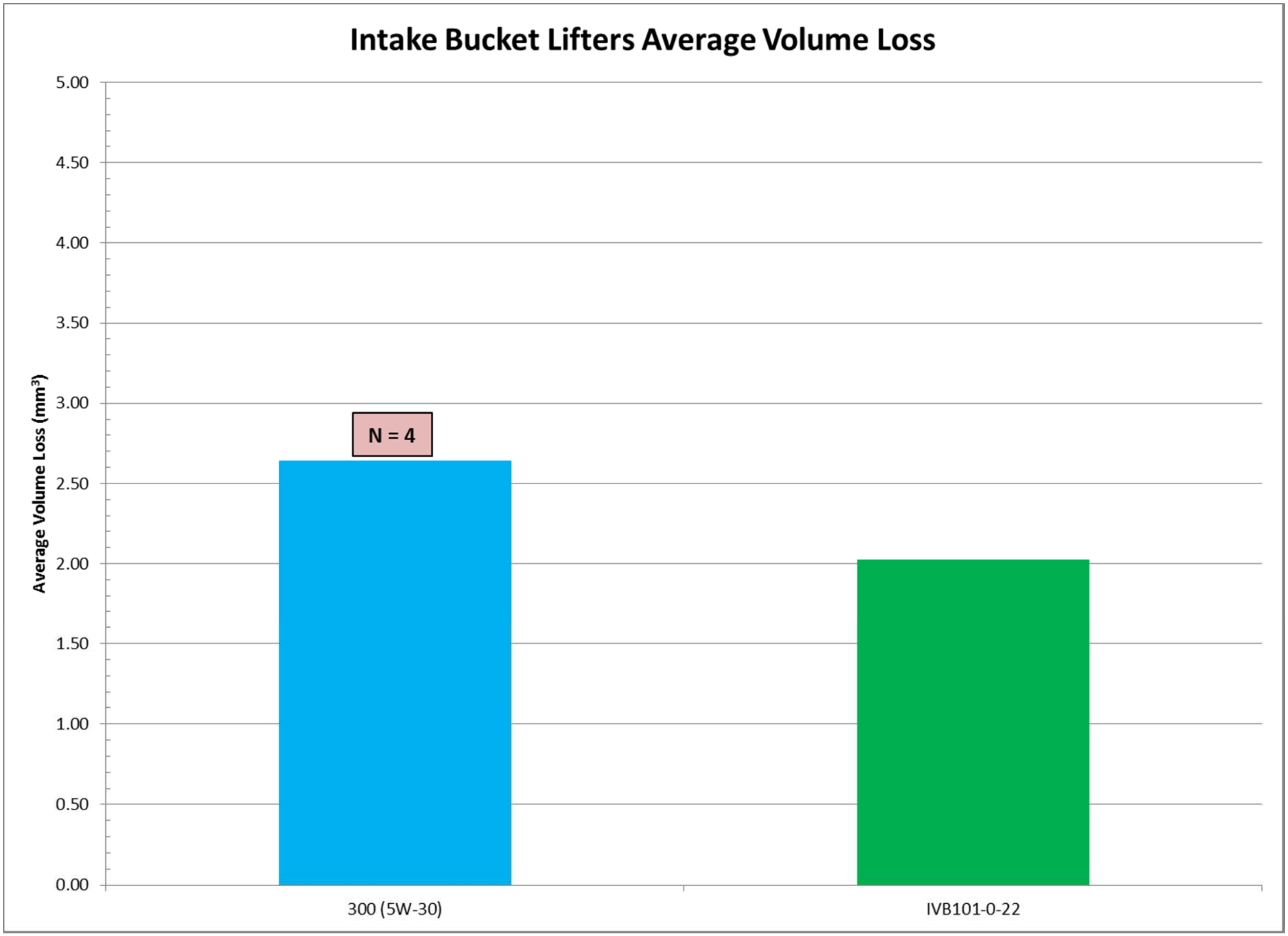


Intake Camshaft Lobe Failure Issue

TOYOTA



Intake Camshaft Lobe Failure Issue

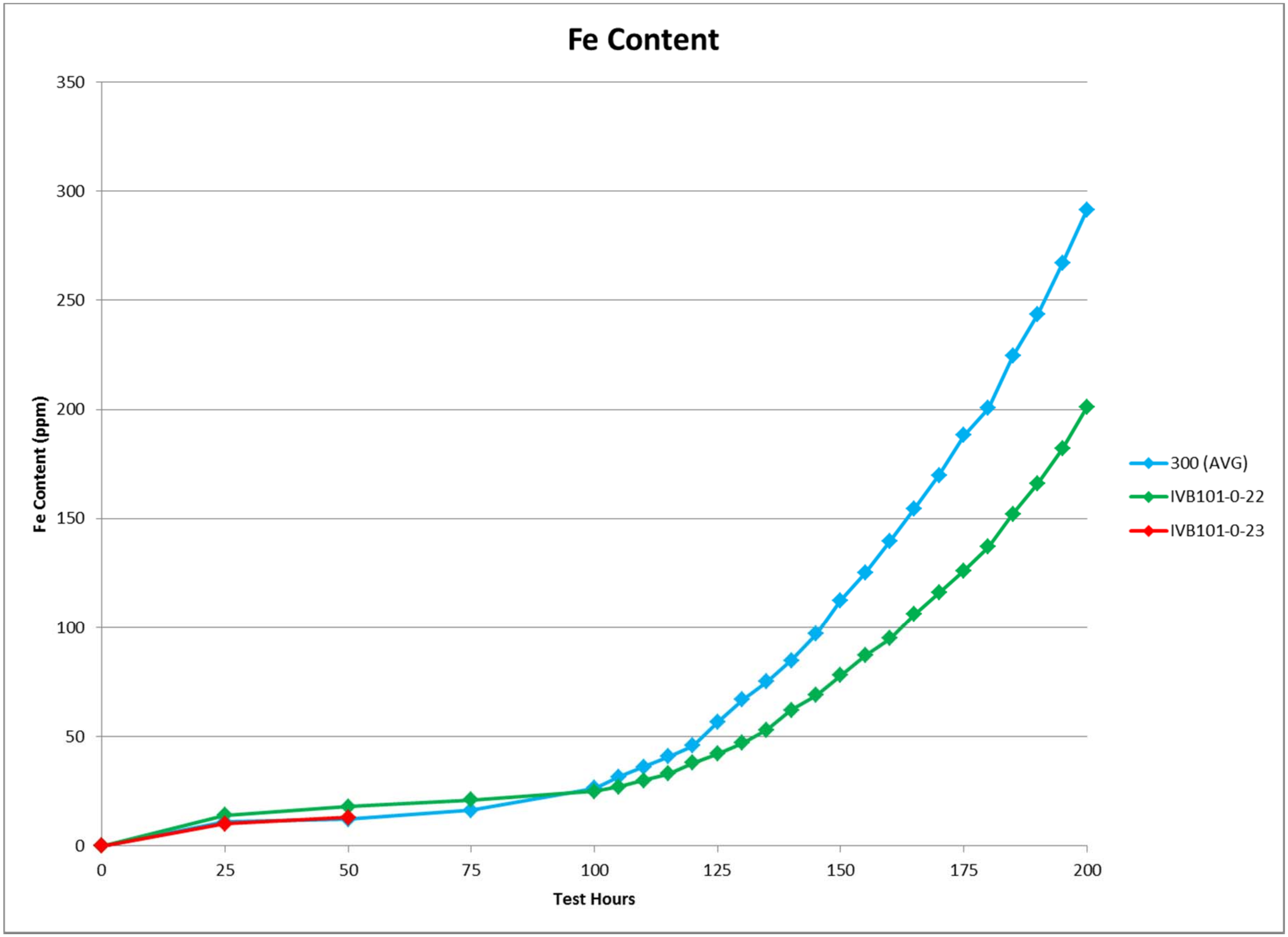


TOYOTA

- Third revised hardware combination: low entrainment lobe profile and medium hardness lobe surface (**<u>HV450</u>**) intake camshaft + **<u>production</u>** tension intake valve springs
  - 1 development tests currently running
  - 1 test at Intertek on stand 101 using ASTM REO 300
    - Has completed 75 hours as of 10:45pm, 10/26/15
    - No intake lobe failures have occurred up through 75 hours
  - 1 development test to start
  - 1 test at Lubrizol using ASTM REO 300

Intake Camshaft Lobe Failure Issue

TOYOTA



- **Go to Oronite failure analysis presentation…**

Intake Camshaft Lobe Failure Issue

TOYOTA

- Other areas under investigation:
  - Pre-test surface roughness of lifters and camshaft lobes (SwRI)
    - Statistical analysis indicates no significant surface roughness differences between lifters or camshaft lobes
    - Statistical analysis indicates no significant correlation between pre-test camshaft lobe Ra, Rsk and/or lifter Ra, Rsk, with camshaft lobe failures
  - Oil distribution along the camshaft (SwRI)
    - Videoed with borescope camera
    - Observed that oil distribution is plentiful at all journal positions
  - Lifter rotation (SwRI)
    - Videoed with borescope camera
    - Observed inconsistent intake lifter rotation between positions within an engine and between engines
    - Exhaust lifters currently being videoed
    - Will compare intake to exhaust lifter rotation
    - Concern that slow or no lifter rotation could be the root cause of lobe failures
    - Investigating what could inhibit lifter rotation
    - **Go to videos…**

- Other areas under investigation:
  - Valve spring pressure at installed height and compressed height (SwRI)
    - Measurements indicate no significant differences exist
  - Installed valve spring height (SwRI)
    - Measurements indicate no significant differences exist
  - Out-of-round of used lifters and bores (Intertek)
    - Measurements did not find any significant out-of-round lifters or bores
  - Hardness of used lifter surfaces (SwRI)
    - Measurements indicate no significant differences exist
  - Oil delivery on used engines (SwRI)
    - Yet to be evaluated
  - Lifter clearance when engine is hot (SwRI)
    - Yet to be evaluated

TOYOTA

- Toyota had a batch of 60 low entrainment production hardness intake camshafts manufactured
  - This batch is started to arrive at the labs
- Toyota has ordered a batch of 200 intake camshaft castings, which will be held prior to the machining and hardening steps in the manufacturing process
  - This will reduce lead time once the intake camshaft design has been finalized
- Toyota is ordering a batch of 300 production tension intake valve springs

Wear Measurement Round-Robin

TOYOTA

- Continuing lifter wear measurement round-robin work at Intertek, Lubrizol and SwRI
  - Labs have conducted Keyence repeatability experimentations and investigations to help understand the results of 1st round-robin
  - Conducted a Keyence metrology meeting on 7/30/15, hosted by Lubrizol
  - Keyence representative participated at the 7/30/15 meeting and provided several recommendations to the labs
  - Several items for the Keyence lifter volume loss measurement procedure have been identified as potentially affecting repeatability and reproducibility
  - A prototype lifter locating fixture for the Keyence has been designed and manufactured by OHT and was received at Intertek on 9/9/15
  - A 2nd round-robin has been designed for the revised Keyence procedure and is progressing at the labs
  - The Keyence procedure revisions will be finalized based on the results of the 2nd round-robin and the appropriate sections of the test procedure draft will be updated

Status of Precision Matrix Labs

TOYOTA

- Status of Intertek and SwRI
  - Both have completed the minimum required prove-out tests, with acceptable results
    - All conducted on the original hardware combination
- Status of Lubrizol
  - 5 prove-out tests completed to-date, 1 on ASTM REO 300 and 4 on ASTM REO 1006-2, but all have been severe
    - All conducted on the original hardware combination
  - All areas evaluated to-date, including operational controls, test engine, break-in, aging and build effects have not improved reproducibility between Lubrizol and the 2 independent labs
    - Using ASTM REO 1006-2 for comparison testing
    - 4 ASTM REO 1006-2 tests completed to-date have produced very repeatable results for intake lifter average area loss and average volume loss

Status of Precision Matrix

TOYOTA

- Toyota has donated all consumable test hardware, with the exception of the camshafts and lifters, for the precision matrix
  - Eliminates MOA funding issues for the IVB
  - Batch controlled hardware still will be sourced through OHT
- Additional prove-out testing is likely to be required at all 3 precision matrix labs due to changes that will be implemented to resolve the intake camshaft lobe failure issue
- Best estimate, based on success using the low entrainment lobe profile and medium hardness lobe surface (HV450) intake camshaft + production tension intake valve springs hardware combination, would be precision matrix start in early December 2015
- If a redesign of the intake camshaft or valve springs is required to resolve the lobe failure issue, the precision matrix start will be pushed into 2016

Status of Test Procedure, Engine Assembly Manual, Report Forms and Data Dictionary

TOYOTA

- Continuing work on test procedure and engine assembly manual drafts
  - Test procedure review team conducting conference calls as needed
  - Test procedure draft (sections that can be completed prior to the precision matrix) is completed, with the exception of a few figures
  - Test procedure annex including procedures for labs to properly install and set-up the TEI supplied Golden Stand is currently being drafted
  - Engine assembly manual is close to completion, with a final review expected soon
  - Test facilitator is close to completion on all test procedure sections and annexes released to-date
  - Drafts will be posted to the ASTM TMC website once completed

Status of Test Procedure, Engine Assembly Manual, Report Forms and Data Dictionary

TOYOTA

Document	Section	Description	Sequence IVA Test Procedure Equivalency	Initial Draft Written	Initial Review Conducted	Status of Revisions	Revisions Completed	Final Draft Review Completed	Accepted for Public Distribution
Test Procedure	Section D	Break-in and Aging Procedure	Section 11	YES	YES	Revision 5 completed and acceptable as the final version for distribution.	YES	YES	YES
	Section E	Engine Operation Procedure	Section 11	YES	YES	Revision 5 completed and acceptable as the final version for distribution.	YES	YES	YES
	Section H	Pre and Post-test Measurements Procedure	Section 12	YES	YES	Revision 4 completed and acceptable as the final version for distribution.	YES	YES	YES
	Keyence Procedure	Keyence Measurements and Calibration Check Procedure	Section 12	YES	YES	Revision 3.4 completed and acceptable as the final version for distribution.	YES	YES	YES
	Section 1	Scope	Section 1	YES	YES	Revision 1 completed and acceptable as the final version for distribution.	YES	YES	YES
	Section 2	Reference Documents	Section 2	To be drafted once necessary information is available.					
	Section 3	Terminology	Section 3	To be drafted once necessary information is available.					
	Section 4	Summary of Test Method	Section 4	YES	YES	Revision 1 completed and acceptable as the final version for distribution.	YES	YES	YES
	Section 5	Significance and Use	Section 5	YES	YES	Revision 1 completed and acceptable as the final version for distribution.	YES	YES	YES
	Section 7	Reagents and Materials	Section 7	To be drafted once necessary information is available.					
	Section 8	Oil Blend Sampling Requirements	Section 8	To be drafted once necessary information is available.					
	Section 10	Data Acquisition, Reference Oil Application, Equipment Calibration and Maintenance	Section 10	YES	YES	Revision 1 completed and acceptable as the final version for distribution.	YES	YES	YES
	Section 13	Test Report	Section 13	YES	YES	Revision 1 completed and acceptable as the final version for distribution.	YES	YES	YES
	Section 14	Precision and Bias	Section 14	To be drafted once necessary information is available.					
	Section 15	Keywords	Section 15	To be drafted once necessary information is available.					
	Annex A1 - A4	ASTM Test Monitoring Center: A1 - Background Information, A2 - Calibration Procedures, A3 - Maintenance Activities, A4 - Related Information	Annex A6	YES	YES	Revision 1 completed and acceptable as the final version for distribution.	YES	YES	YES
	Annex A6	Parts List	Annex A2	YES	YES	Intertek completed initial draft and distributed for advance review. Reviewed on Tuesday, 7/21/15.	NO	NO	NO
	Annex A7	Procedures for lab to properly install and set-up the TEI supplied Golden Stand	Section 9	In Process	NO	SwRI working on initial draft, with assistance, if needed. Will distribute for advance review. Will review once available.	NO	NO	NO
	Annex A8	Fuels Specification Information	Annex A4	YES	YES	Revision 1 completed and acceptable as the final version for distribution.	YES	YES	YES
	Annex A5	Safety Precautions	Annex A5	YES	YES	No revisions from IVA procedure required and carry-over from the IVA procedure acceptable as the final version for distribution.	YES	YES	YES
Engine Assembly Manual	Section 1	New Engine Preparation	Section 6, 9	YES	YES	SwRI completed and distributed Revision 2. Final review due.	NO	NO	NO
	Section 2	Camshaft and Lifter Installation	Section 6, 9	YES	YES	SwRI completed and distributed Revision 6. Final review due.	NO	NO	NO
	Section 3	Cylinder Head Replacement	Section 6, 9	YES	YES	SwRI completed and distributed Revision 6. Final review due.	NO	NO	NO

Status of Test Procedure, Engine Assembly Manual, Report Forms and Data Dictionary

TOYOTA

- Report forms and data dictionary have been completed and implemented
  - Currently using IVB VERSION 20150707
  - Next revision will occur after completion of the precision matrix

Attachment 7

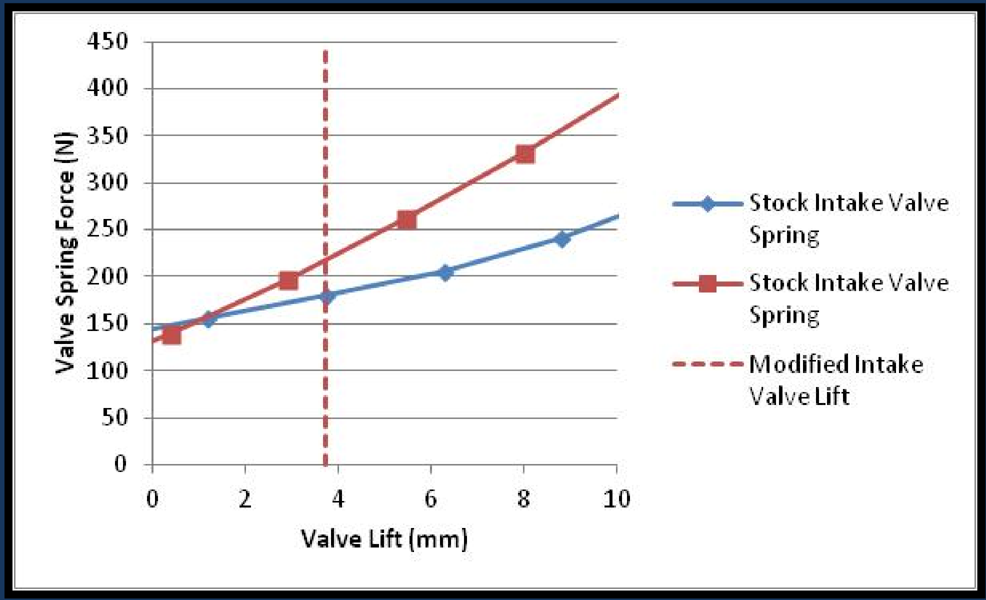
EFFECT OF VALVE SPRINGS ON LIFTER ROTATION IN SEQUENCE IVB

Eric Liu, Sr. Research Engineer

Southwest Research Institute

October 26, 2015

Stiff vs. Production Springs



- Stiffer spring increases spring force by ~30% over production spring at max valve lift (for modified intake cam lobe profiles)
- Stiffer springs are ~12mm shorter than production springs

Stiff vs. Productions Springs @ 800rpm

Position	Rotation?		Slow/Fast?		Direction	
	Stiff	Stock	Stiff	Stock	Stiff	Stock
1	Y	Y	F	F	CCW	CW
2	N	Y	--	S	--	CCW
3	Y	Y	S	S	CCW	CCW
4	Y	Y	S	S	CCW	CCW
5	Y	Y	F	F	CW	CW
6	N	Y	--	S	--	CW
7	Y	Y	F	F	CW	CW
8	N	N	--	--	--	--

Stiff vs. Productions Springs @ 4000rpm

Position	Rotation?		Slow/Fast?		Direction	
	Stiff	Stock	Stiff	Stock	Stiff	Stock
1	Y	?	F	--	CCW	--
2	Y	Y	S	F	CCW	CCW
3	Y	Y	S	F	CCW	CCW
4	Y	Y	S	S	CCW	CCW
5	Y	Y	F	F	CW	CW
6	Y	Y	S	F	CCW	CW
7	Y	Y	S	F	CCW	CW
8	Y	N	S	--	CW	--

Stiff vs. Productions Springs @ 800-4300rpm Transitions

Position	Rotation?		Slow/Fast?		Direction	
	Stiff	Stock	Stiff	Stock	Stiff	Stock
1	Y	Y	S→F	--	CCW	--
2	Y	Y	S→F	S→F	CCW	CCW
3	Y	Y	Stop→S→F	S→F	CCW	CCW
4	Y	Y	S→F	S→F	CCW	CCW
5	Y	Y	F	S→F	CW	CW
6	Y*	Y	--	S→F	CW→CCW	CW
7	Y*	Y	--	S→F	CW→CCW	CW
8	Y	Y*	--	--	CW→CCW	CW→CCW

*Some lifters did not make full rotations; they rotate ~90 deg in one direction and rotate back to original orientation.

Stiff vs. Productions Springs @ 800-4300rpm Transitions

Position	Rotation?		Slow/Fast?		Direction	
	Stiff	Stock	Stiff	Stock	Stiff	Stock
1	Y	Y	S→F	--	CCW	--
2	Y	Y	S→F	S→F	CCW	CCW
3	Y	Y	Stop→S→F	S→F	CCW	CCW
4	Y	Y	S→F	S→F	CCW	CCW
5	Y	Y	F	S→F	CW	CW
6	Y*	Y	--	S→F	CW→CCW	CW
7	Y*	Y	--	S→F	CW→CCW	CW
8	Y*	Y*	--	--	CW→CCW	CW→CCW

*Stock valve springs appear to make lifter rotation more consistent during transitions

Effect of Valvespring Orientation on Lifter Rotation

- Flipped valve spring from right-side-up orientation (A) to upside-down orientation (B)

Position	Rotation?		Slow/Fast?		Direction	
	A	B	A	B	A	B
8	Y*	Y	--	--	CW→CCW	CW

Orientation A

Orientation B

Effect of Valvespring on Lifter Rotation Direction

- Swapped spring 4 (CCW) with spring 5 (CW) to spring effects on lifter rotation direction

Position	Rotation?		Slow/Fast?		Direction	
	Not Swapped	Swapped	Not Swapped	Swapped	Not Swapped	Swapped
4	Y	Y	S→F	S→F	CCW	CCW
5	Y	Y	S→F	S→F	CW	CW

- No effect on lifter rotation direction
- Lifter rotation direction most likely dictated by something else:
  - Cam lobe offset due to camshaft endplay
  - Asymmetric lifter surface topography

Other Observations

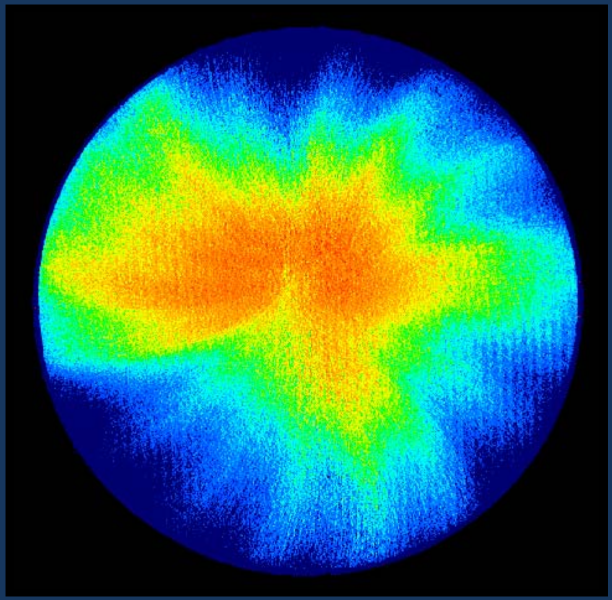
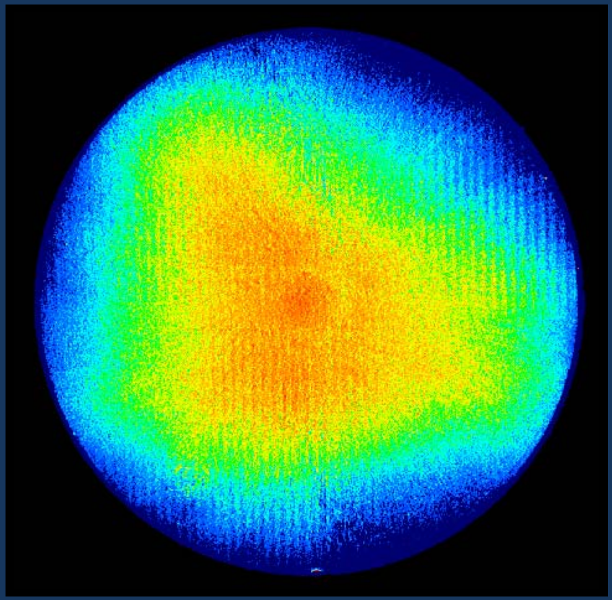
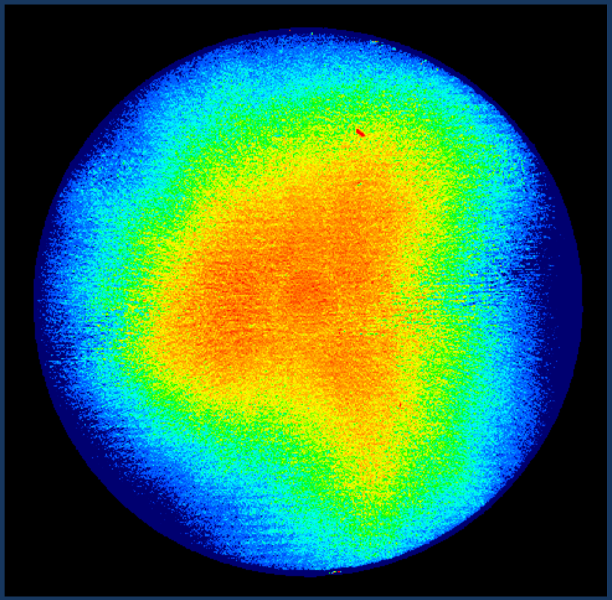
- Marked valvespring and retainer with white marker before testing to track valve spring rotation
- Valvespring does not rotate with respect to engine and retainer
- Lifter most likely lifts off from valve stem to rotate

Conclusions

- Valvespring orientation apparently has an effect on lifters that are not rotating
- Lifter rotation direction most likely caused by something other than valvespring

Proposed Hypothesis on Lifter Rotation

- Potential causes:
  - Valvespring orientation
  - Camshaft end-play
  - Asymmetric lifter surface topography

What Can We Do About This?

- Open discussion…

Acknowledgments

- Mike Moneer
- Fred Gerhart
- Carlton Coker
- Peter Lee

Questions

Thanks you for your time…

Attachment 8

Seq. IVB cam failure analysis

Presented to Sequence IV Surveillance Panel Meeting

10/27/2015

ADDING UP™

Seq. IVB intake cam failure issue

- Possible cause of failure
  - Oil technology
  - Cam hardware
  - Operational
- Metallurgical analysis - cam and lifter hardware construction
- Wear analysis – failed cams
- Wear analysis – tappets
- Possible causes of stopping of tappet rotation

Possible cause of failure – oil technology

- Seq. IVB development team reviewed the failed cam oil data.
  - 3 reference oil runs: SD/SE, 1006-2, TMC300
  - 10 candidate runs: 8 oils
  - Occurred at both independent labs, different stands, different oil viscosity grades.

- Further analysis on IVB data (with and without cam failure including all variables that characterize each test) by statistician pending, to identify the next step:
  - Fail rate
  - Engine hour impact
  - Impact from other operational factors

Possible cause of failure – Cam hardware

- 4 sets of normal/failed camshafts & lifters that ran on the same oil were examined
- Metallurgical analysis were carried out on the camshaft and lifters by both SWRI and Chevron Oronite in order to determine the presence of any manufacturing differences on hardware (e.g. incomplete heat treatment of the camshaft). It was found that:
  - Lifter surface hardness (HV800) is close to the production cam lobes (HV900, from 2012) and significantly higher than the test cams (HV450). However, the microstructure difference is due to heat treatment, and no notable differences in hardened layer thickness or hardness across different cam lobes for both cam types.
  - Some lobes has undergone enough wear for the hardened layer to be completely removed. Once the hardened layer is worn away, the bulk of the cam which consists mainly of grey cast iron would wear at a faster pace resulting in the complete removal of the cam nose.
  - While the passing test have circular scratches and a symmetric wear pattern indicating full and constant rotation of the tappets, the wear scars from the failing test appear to having a ~rectangular or line wear scar within the circular polished area, indicating increased wear due to stopping of rotation and the sliding of cam nose on the surface of the tappet.
- On 9/30/2015, development test IVB101-0-21 run on low entrainment production hardness cam with TMC300 terminated at 153hrs due to cam failure. This also indicates that the lobe surface hardness is not the root cause of the lobe failures. (also the first lobe failure to occur with TMC300)

Possible cause of failure – Operational (tappet rotation)

- While the passing tests have circular scratches and a symmetric wear pattern indicating full and constant rotation of the tappets, the wear scars from the failing test appear to having a rectangular or line wear scar within the circular polished area, indicating increased wear due to stopping of rotation and the sliding of cam nose on the surface of the tappet.
- 2 more development tests (IVB101-0-20, 1006-2; IVB101-0-22, TMC300) were also performed on low entrainment production hardness cam without cam failure.
- Possible causes of impediment of the rotation of tappets at some (or all) speeds:
  - Reduce traction at cam-tappet contact: if cam geometry changes vibration.
  - Integrated Shim – Valve Stem End: excessive contact stress can impede the rotation of the tappet.
  - Tappet Wall – Engine Block: deposit (not much in this case), block distortion etc.
  - Tilting of tappet: caused by tappet housing wear and other misalignment issues.
  - Additive chemistry: Although additive chemistry could impact rotation of tappets in some rare cases, this is not the cause here shown by the repeats of same oils.

Cam and Lifter Construction - Metallurgical Analysis

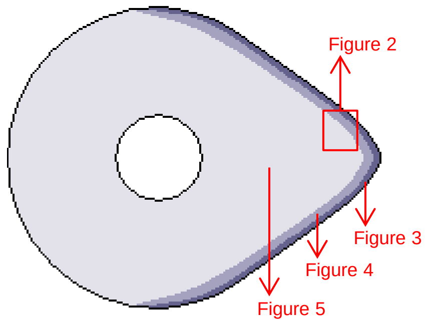
- Metallurgical Analysis: The metallurgy and construction of the test cams was compared to the production version of the same cams. It was observed that:
  1. Both cams have undergone case hardening. Case hardening in the production cams appears to have been achieved through surface melting resulting in a ledeburite outer case with a hardness of about HV900. The case hardening process used for the test cams appears to have been induction hardening resulting in a case microhardness of about HV450 which is 50% less than that of production cams.
  2. The microstructure of the core in the case of the examined production cam shaft was found to be grey cast iron with type A graphite flakes (i.e. large, randomly oriented graphite flakes) in a predominantly pearlitic matrix. The examined test cam also had a mostly pearlitic grey cast iron core. It was however observed that the graphite structure of the cast iron in this case consists of type D graphite (i.e. fine, dendritic clusters of graphite flakes) across most of the profile of the cam lobes except near the very center of each lobe where the dendritic clusters of type D graphite give way to a type A graphite structure observed in the production cams. This difference is more than likely due to small differences in the cooling rates during the casting process and does not significantly affect mechanical properties.
  3. While in the production cams (with a larger entrainment angle), the hardened case is only present on the nose side of the cam extending about 90 degrees to either side of the nose, the test cams have been case hardened along the entire surface of the cam including the base circle of the cam (unlike the production cam).

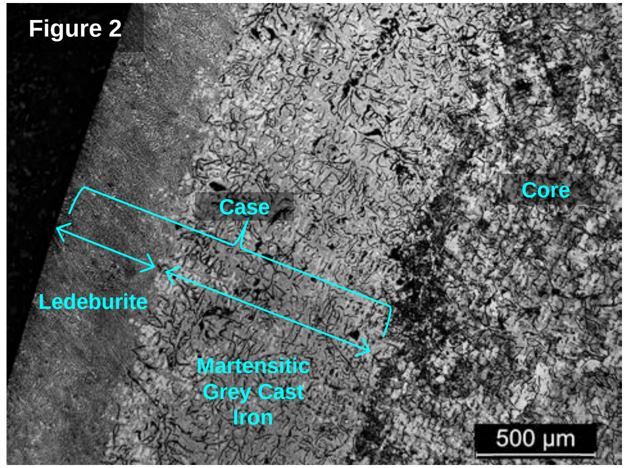
Cam and Lifter Construction - Metallurgical Analysis

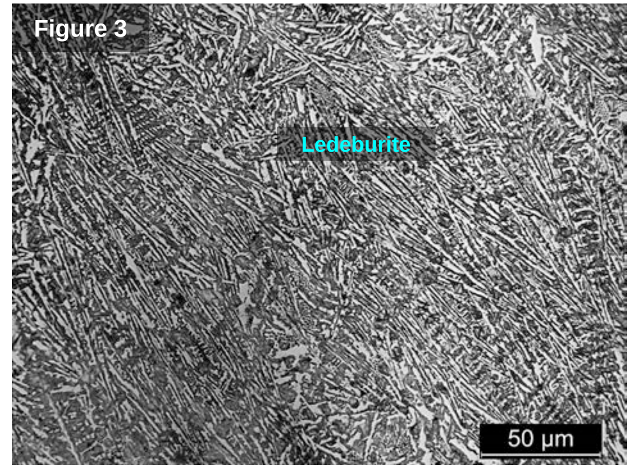
- The lifters (tappets) in this engine have also been case hardened. The microstructural observations and the microhardness profiles of these tappets appear to suggest that nitriding was the likely case hardening process used. The hardness on the surface of these tappets is consistently measured to be about HV800.
- The surface hardness of the lifters (i.e. HV800) is quite close to the surface hardness of the production cams on the nose side of the lobes (i.e. HV900) and significantly higher than the surface hardness of the test cams (with low entrainment angle, i.e. a blunter nose) which is about HV450.

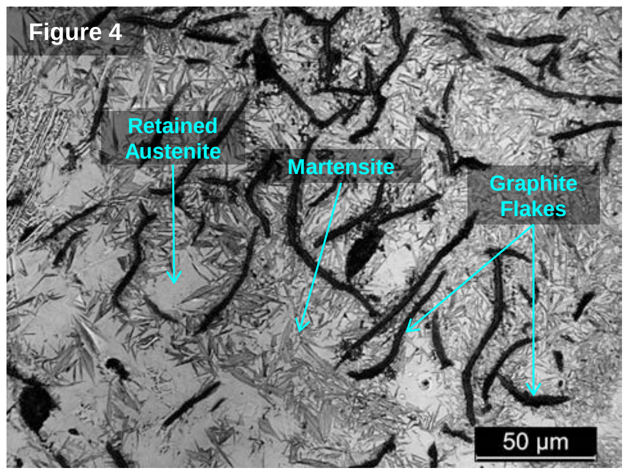
Microstructure: Production Cams

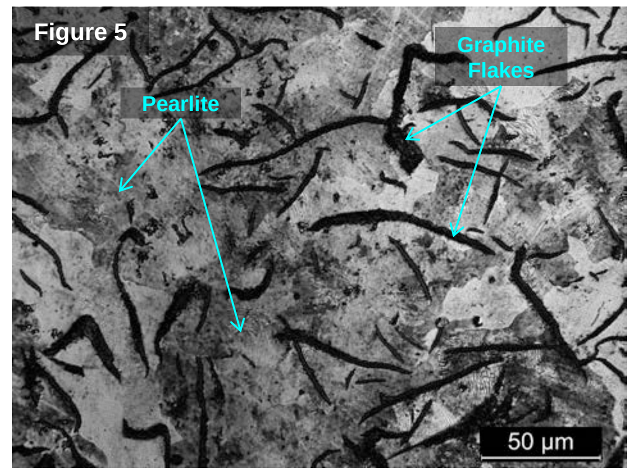
Figure 1











Probing the microstructure of a production cam lobe (provided by Toyota in 2012) reveals a case hardened grey cast iron microstructure. Case hardening in this case appears to have been achieved by laser surface processing (laser surface melting in this case) which has resulted in three distinct microstructural layers as shown the schematic of figure 1 and the low magnification metallograph of figure 2 capturing all three layers.

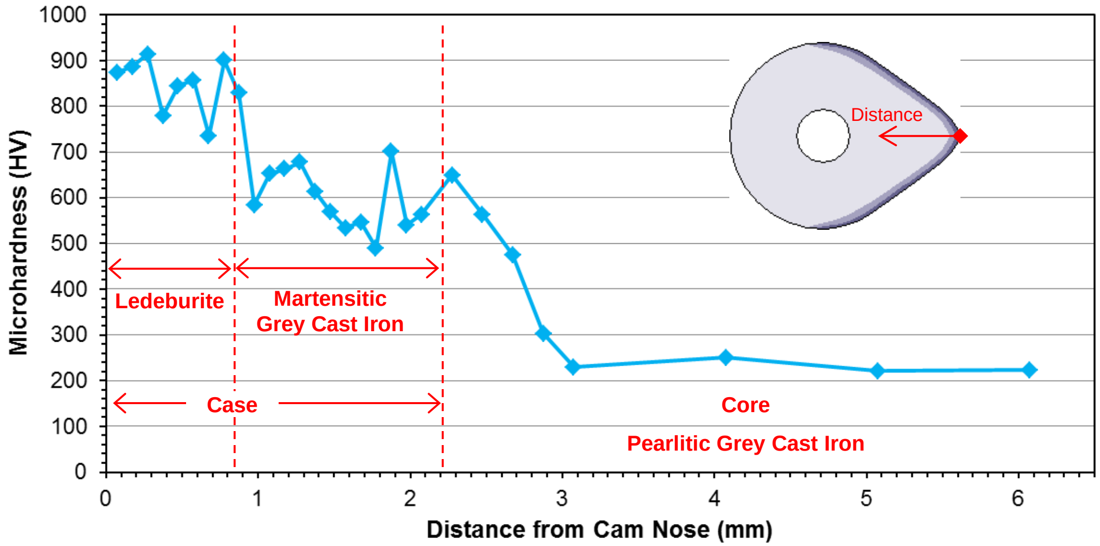
The outer layer is about 0.5mm thick is predominantly feathery ledeburite consisting of cementite (carbide) and martensite. The microstructure of this layer is shown in the micrograph of figure 3.

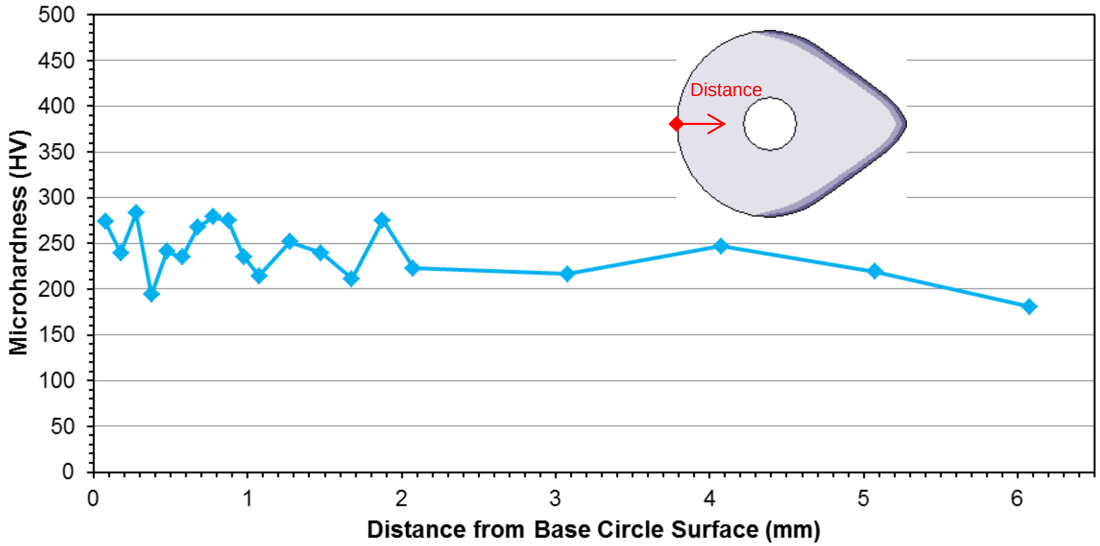
Below the top ledeburite layer is a 1mm thick layer of grey cast iron consisting of retained austenite (white constituent) and martensite matrix (figure 4).

The microstructure of the second case layer is the result of exposure to heat and martempering of the alloy during the hardening process.

The microstructure of the bulk of the cam lobe beyond the hardened case layers is shown in the micrograph of figure 5 and shows a typical grey cast iron structure with type A graphite (i.e. randomly oriented large flakes) in a pearlitic matrix and small volumes of free ferrite. This is the as-cast structure of this camshaft. Case hardening, as shown in the schematic of figure 1 is only done on the nose side of the cam lobe. No case hardened layer was observed in on the surface of the base circle of the cam lobe.

Microhardness: Production Cams





Microhardness measurements (Vicker's scale) are made across the profile of parts (after metallographic preparation of each part) across their cross section in regular distance intervals. Measurements are made at smaller intervals near the tip of the cam nose (as well as lifters) in order to more accurately identify the thickness of hardened layers. The distance between indents is maintained at larger than twice the diameter of the foot print of indents in order to avoid the plastic deformation zone and work hardening effects of neighboring indents affect the readings.

The microhardness values measured on the across the nose of the cam is shown in the top graph. The hardness near the surface is about HV900 which is consistent with the ledeburite structure observed on the surface (see previous page). Through the second layer of the case (martensitic grey cast iron) the hardness is about HV600 (again consistent with the observed microstructure). The core (pearlitic grey iron with type A graphite) has a hardness of about HV250.

The microhardness values measured across the surface of the base circle (lower graph) hover around HV250 as no case hardening has occurred in this region and the microstructure is that of the pearlitic case iron observed in the bulk of the cam lobe. The small fluctuations closer to the surface here are due to the work hardening effects of the machining process.

Microstructure: Test Cams

Figure 1

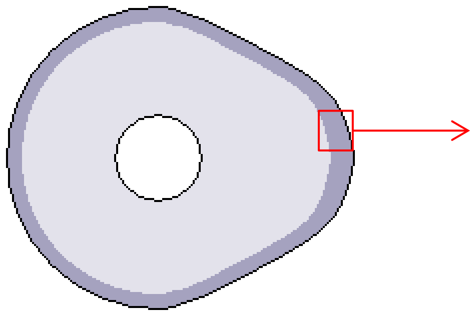


Figure 2

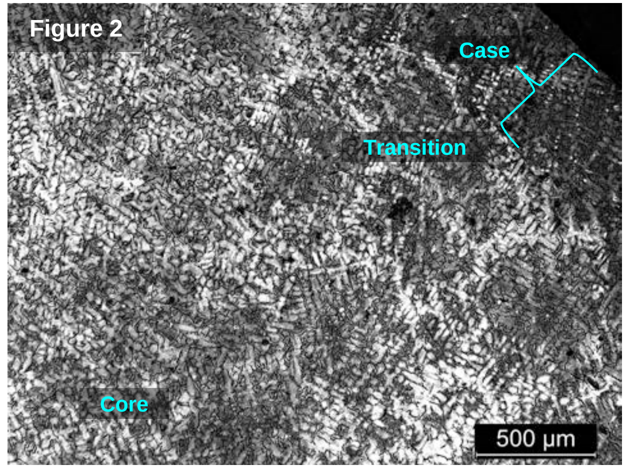


Figure 3

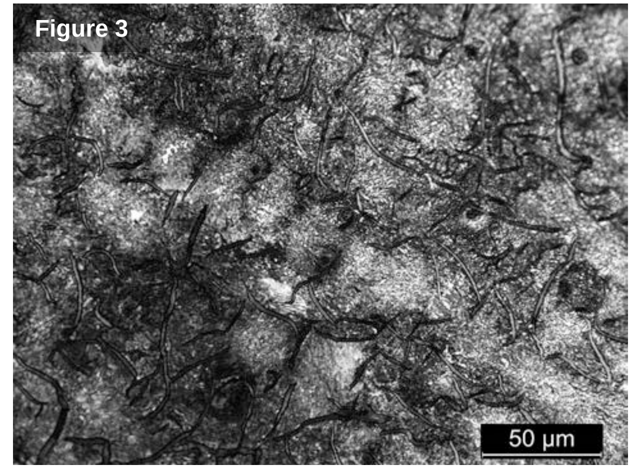


Figure 4

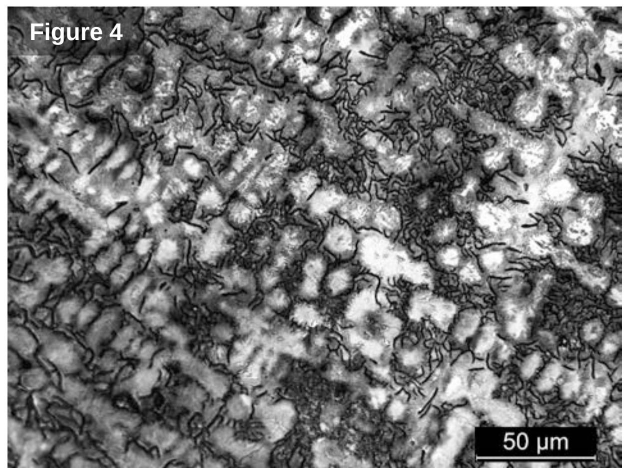
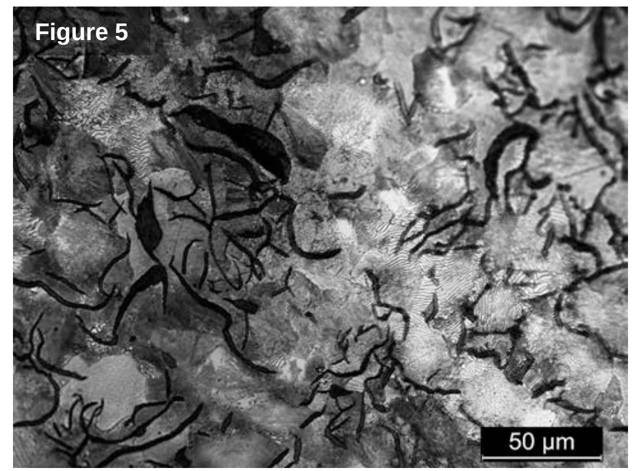


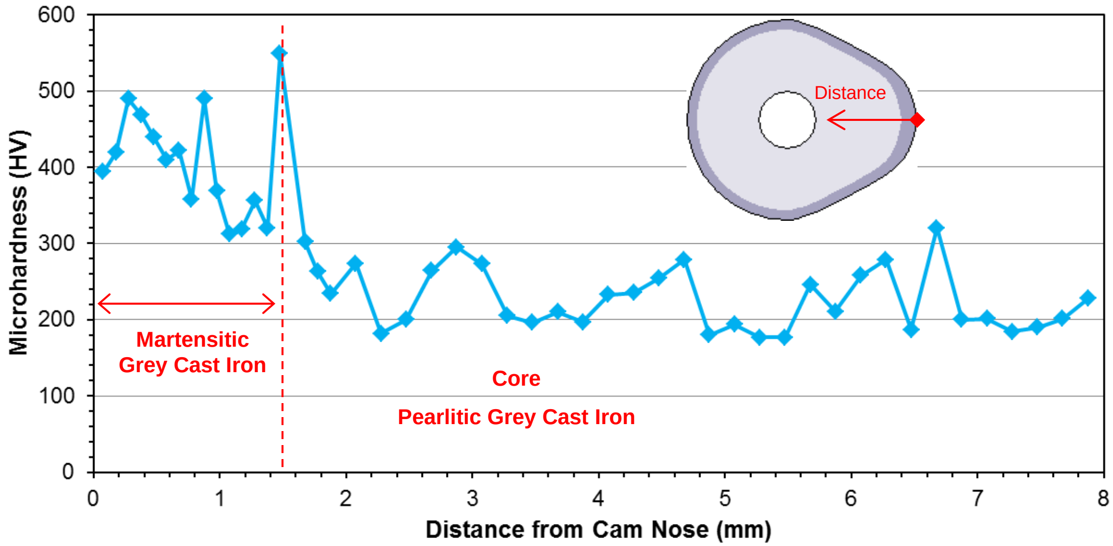
Figure 5

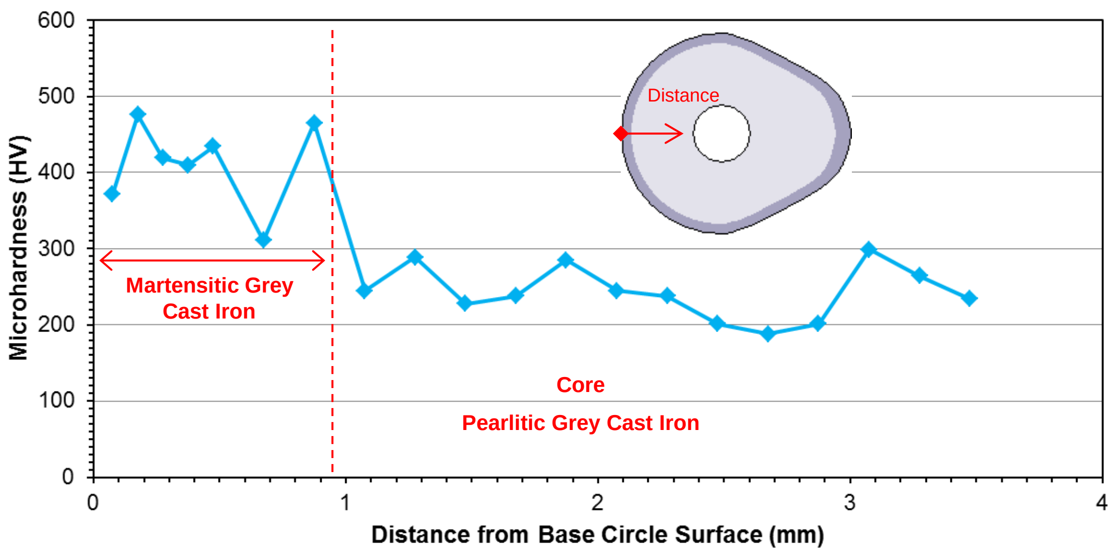


The microstructure of the test cams (used at Intertek and SWRI) also consists of a case hardened structure typically seen in flame hardened or induction hardened grey cast iron specimens. The schematic of figure 1 shows the observation that the case is present through out the entire periphery of the lobe (unlike the production cams discussed in previous pages). The low magnification micrograph of figure 2 encompasses the observed hardened surface layer (case) and the core microstructure. The microstructure of the case (fig. 3) consists of a fine type D (dendritic) graphite network in a martensite and retained austenite matrix (giving the observed HV400 hardness). The microstructure of the transition region between the case and the core mainly consists of similar dendritic graphite in bainite and fine pearlite and small volumes of free carbide (fig 4).

Further away from the surface of the lobe, the microstructure of the core (figure 5) transitions from dendritic graphite in a pearlitic matrix to more of type A graphite flakes also in a predominantly pearlite matrix.

Microhardness: Test Cams

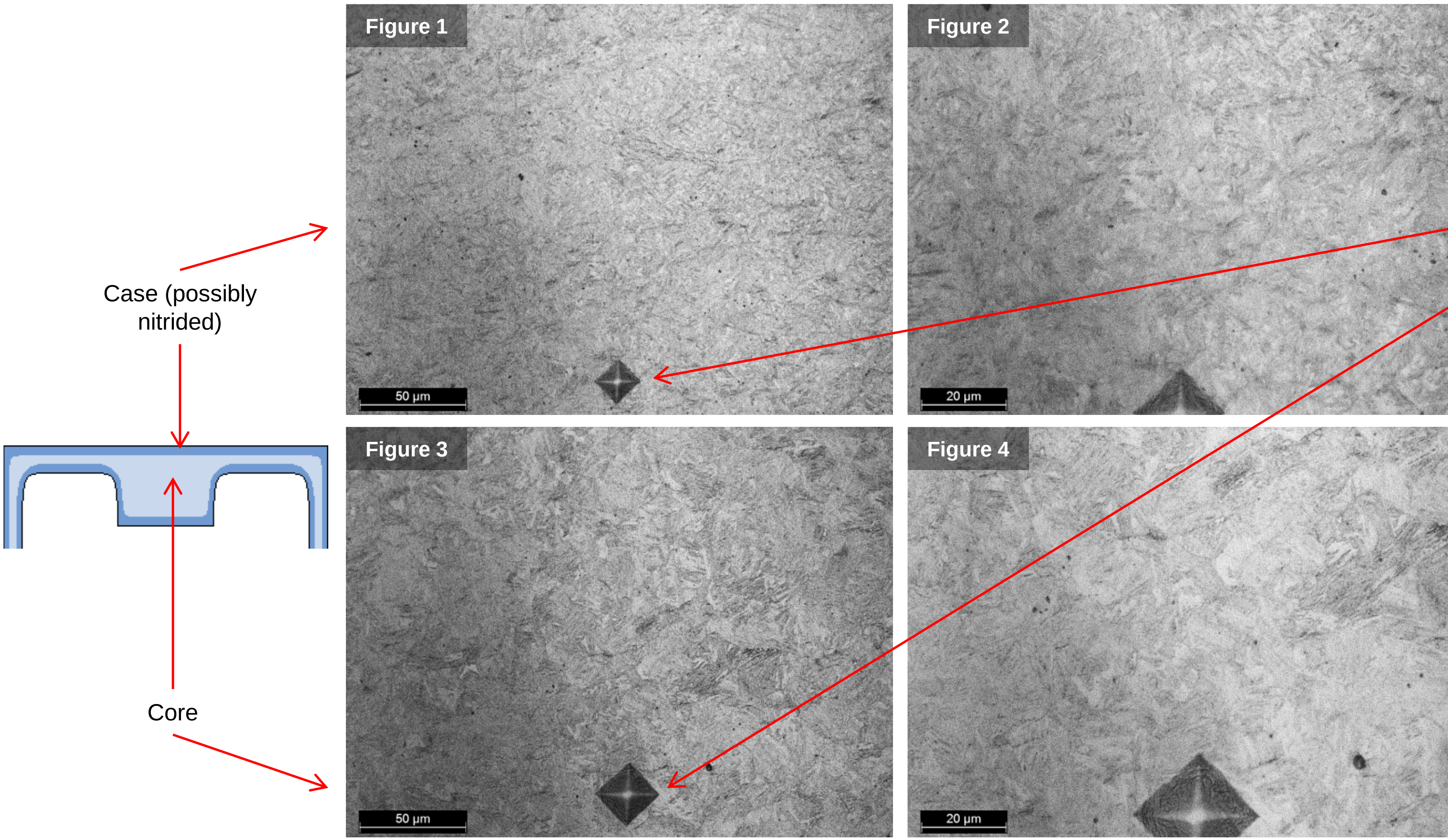




Microhardness is measured across the nose of the test cam similarly to the case of the manufactured cams. The hardness of the hardened case averages around HV450 near the surface and transitions to HV250 in the core (see top graph). Both these values are consistent with the observed microstructure of the came in the case (i.e. martensitic grey cast iron) and the core (pearlitic grey cast iron with type D and A graphite).

As the case hardening is done along the entire surface of the cam, microhardness measurements across the surface of the base circle (lower graph) yield the same values as the measurements across the surface of the cam nose with a slightly thinner hardened case due to geometry of the cam and its effect on heat transfer during the case hardening heat treatment process.

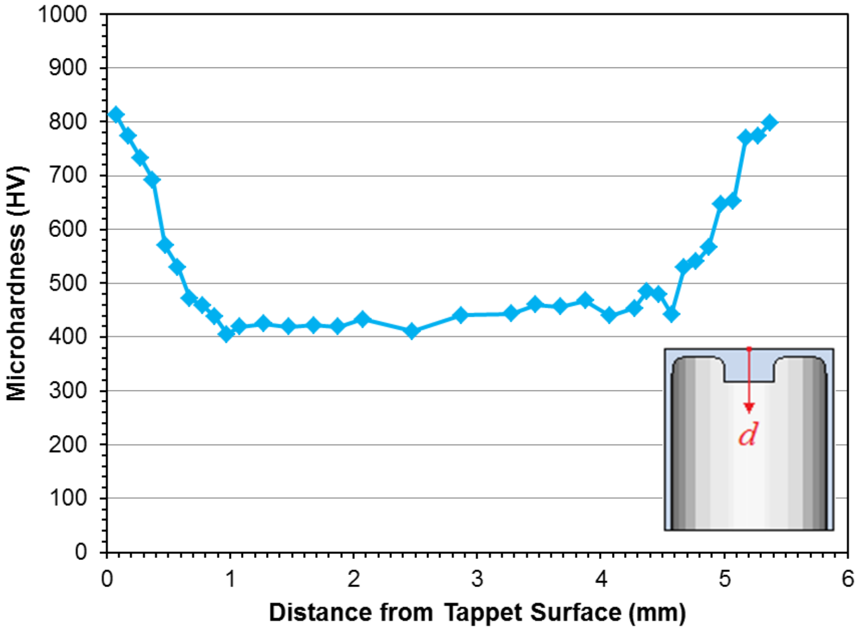
Microstructure: Lifter

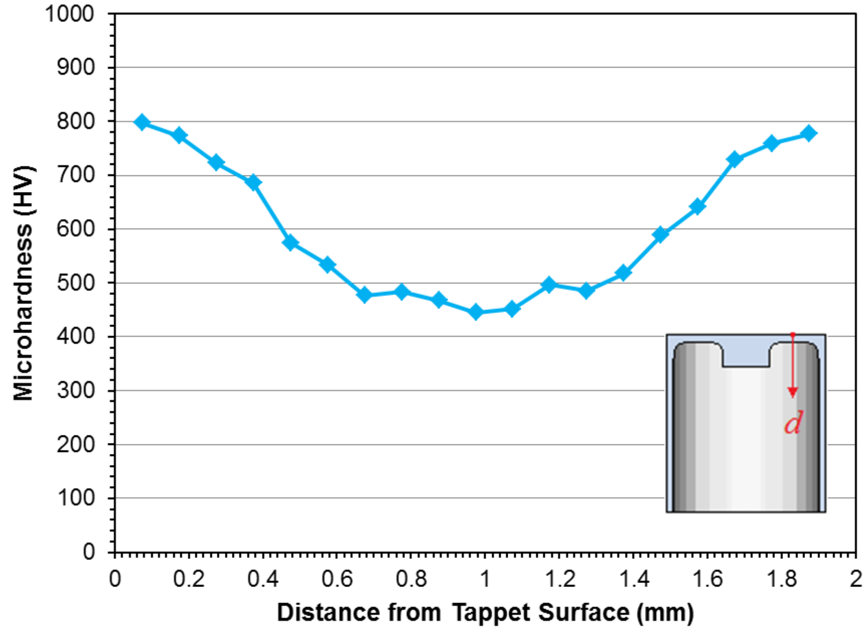


Microhardness measurement indentation marks (same scale/magnification)
Note difference in size of indentation marks in spite of similar microstructure.

Microstructure observed in these micrographs appears to be Widmanstätten Pearlite/Ferrite that has undergone case hardening. The microstructure in case (surface region) is visually identical to the core microstructure (compare figures 1 and 2 with 3 and 4). The etched pattern on the surface (similar to the schematic shown here) as well as the microhardness data (see next page) along the cross section of the tappet suggest the existence of hardened case. The microhardness values measured, along with the microstructural observations shown here point to nitriding as the mostly likely case hardening heat treatment used on this part.

Microhardness





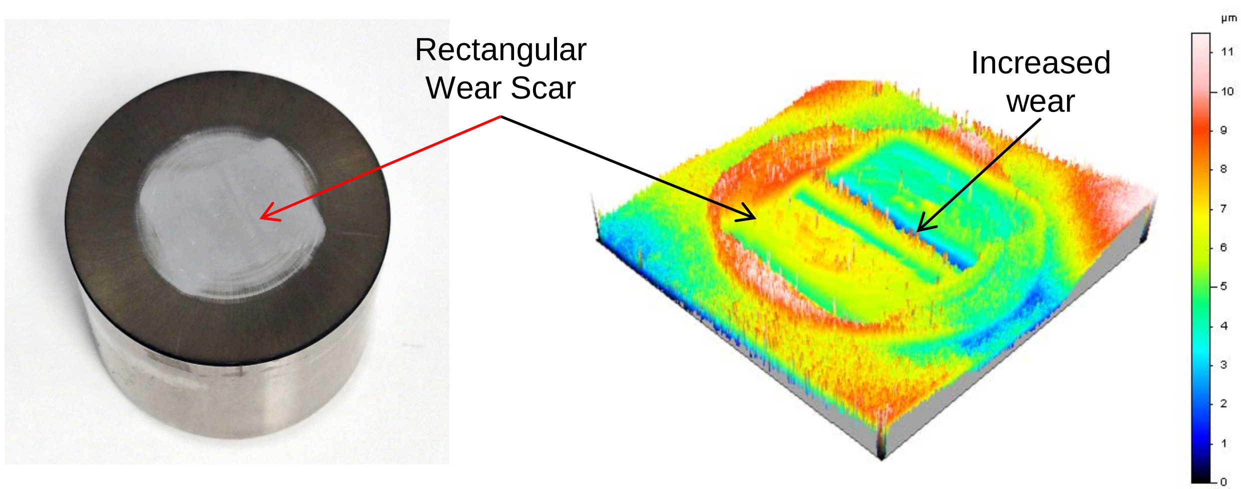
The two graphs shows the microhardness data measured across the cross section of the tappet at two different locations as shown in the schematics that accompany each the graphs. With an average hardness of about 850 HV near the surface, this layer is substantially harder than the core which has an average hardness of about 420 HV (see next page graphs).

Wear Analysis – Failed Cams

- It is impossible to verify the existence of the hardened layer in the microstructure of the severely worn cam lobes but indications are that since case hardening has been done on the surviving cam lobes, it is likely that all the lobes on this camshaft hard undergone the same heat treatment.
- Metallurgical analysis were carried out on the camshaft by both SWRI and Chevron Oronite in order to determine the presence of any manufacturing defects (e.g. incomplete heat treatment of the camshaft). It was found that:
  - Cam lobes were hardened on all contact surfaces and that the hardened layer was present on the surface of all cam lobes.
  - No notable differences in hardened layer thickness and hardness values across different cam lobes.
  - Some lobes has undergone enough wear for the hardened layer to be completely removed. Once the hardened layer is worn away, the bulk of the cam which consists mainly of grey cast iron would wear at a faster pace resulting in the complete removal of the cam nose.
  - Failure had shown as early as 40hrs in test.
- Surface hardness of several tappets was also measured to probe for any inconsistencies. None were found.

Wear Analysis – Tappets

- An examination of the wear scar on tappets reveals a wear pattern indicating lack of rotation in most tappets from the failed test. While the intake tappet of the passing test have circular scratches and a symmetric wear pattern indicating full and constant rotation of the tappets, the wear scars from the failing test, although appearing to have general circular shape, do not have a circular and symmetric topography with some of them having a rectangular wear scar within the circular polished area. The intake tappet 1 from that test is shown here as an example in which the wear scar indicates lack of constant rotation of the tappet during the test. The three dimensional profile of the wear scar clearly shows a rectangular area of increased wear due to stopping of rotation and the sliding of the cam nose on one location on the surface of the tappet.



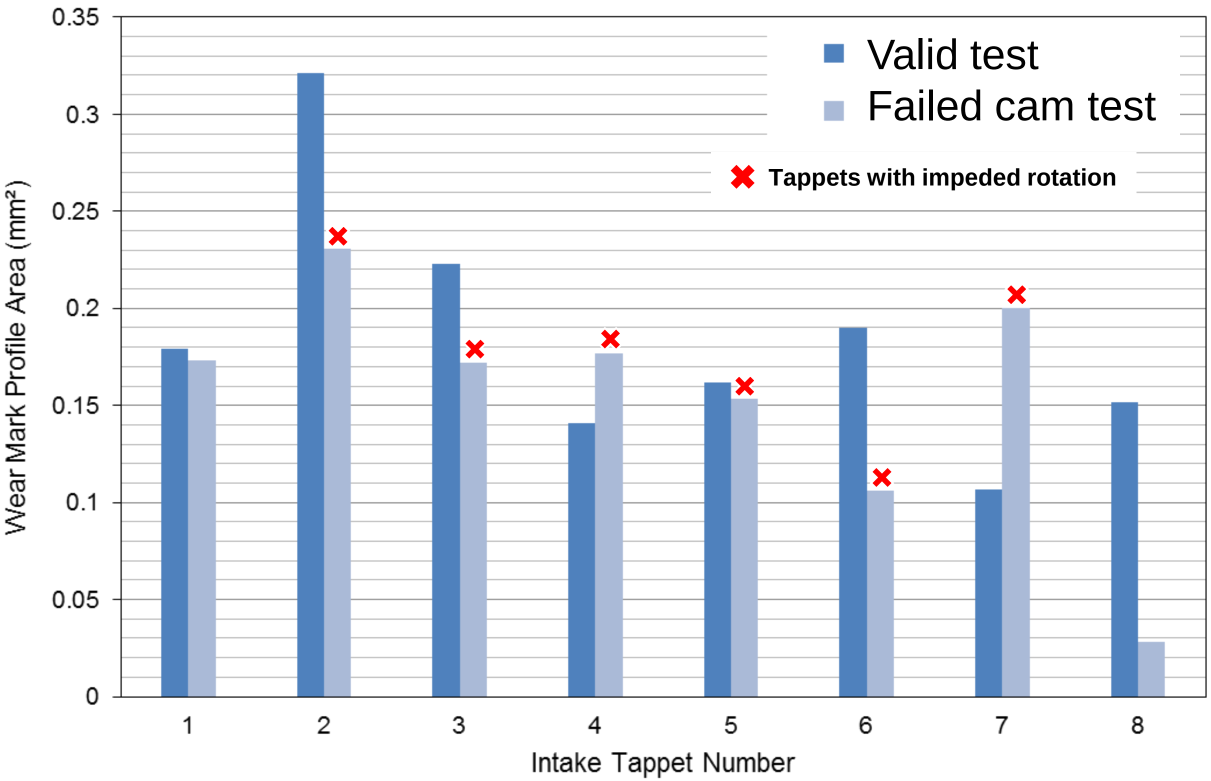
Tappets Survey

- The wear scars on the top contact surface of each tappet as well as the wear scar on the integrated tappet shim were probed to examine any quantitative and qualitative correlation between cam wear and wear at these contacts.

Intake tappets from a failed test

Intake tappets from the corresponding valid test

Tappet Wear: Top Surface



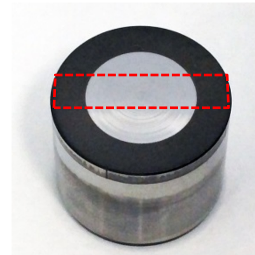


Figure 1

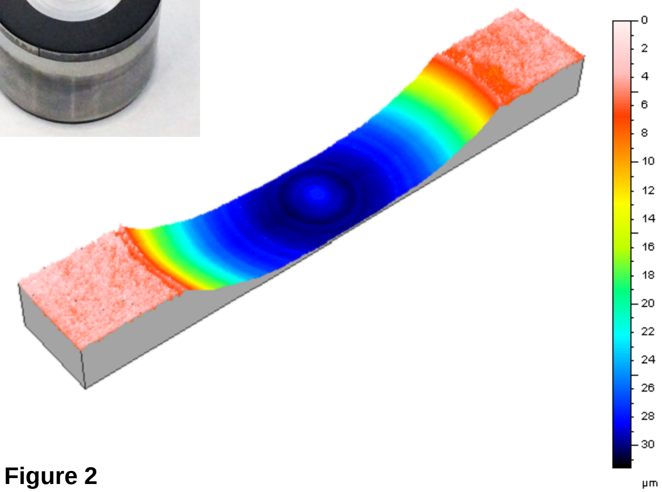


Figure 2

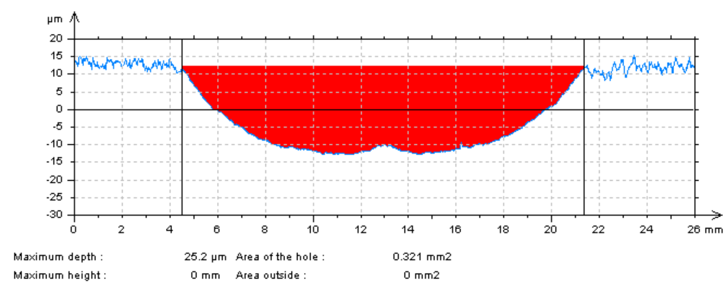
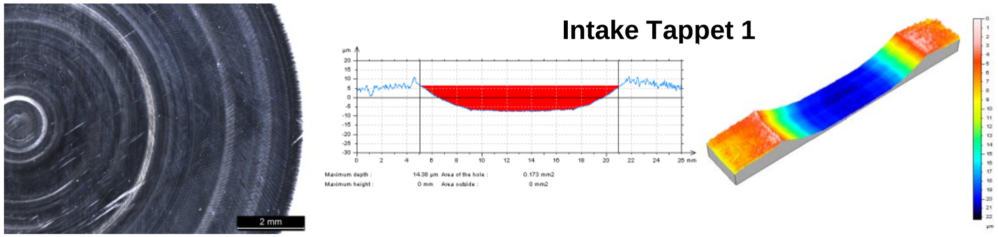


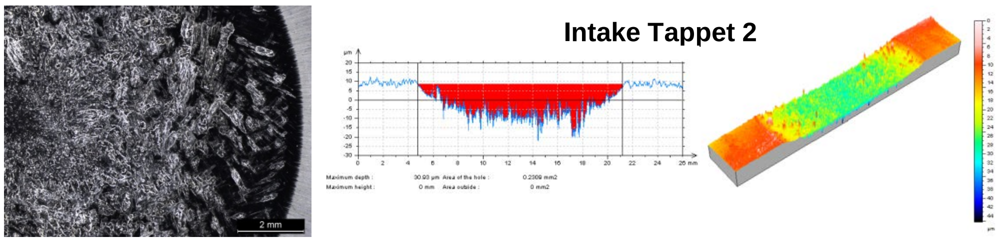
Figure 3

Tappets Analyses: Failed Cam Test

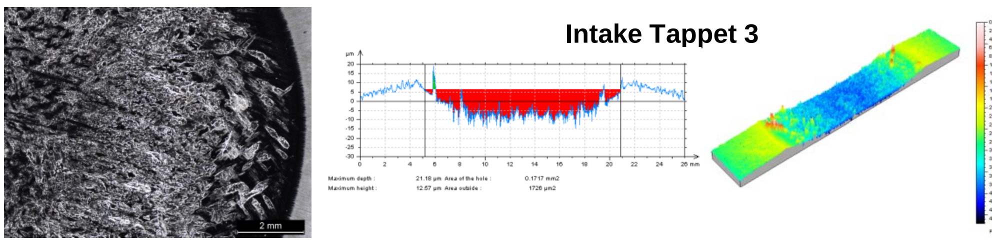
Intake Tappet 1



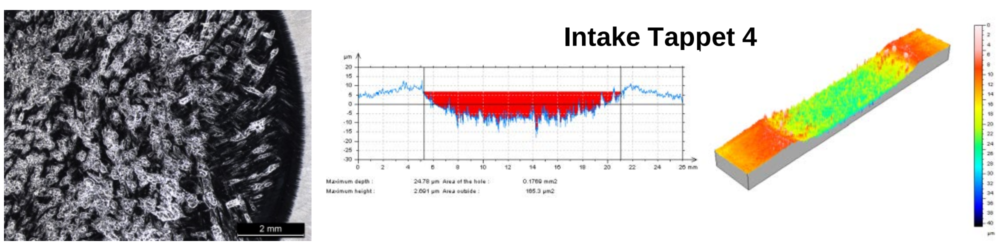
Intake Tappet 2



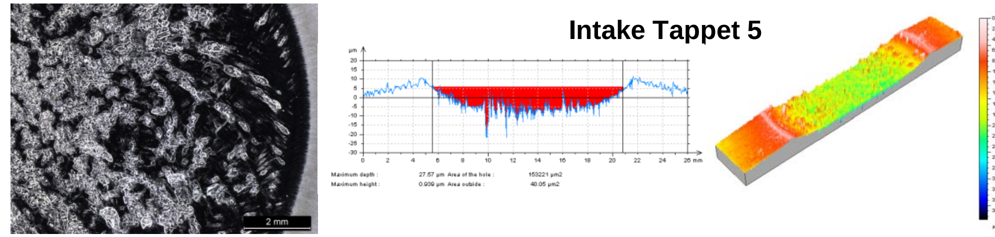
Intake Tappet 3



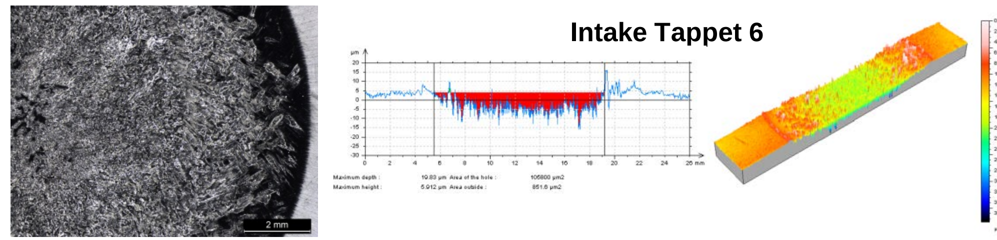
Intake Tappet 4



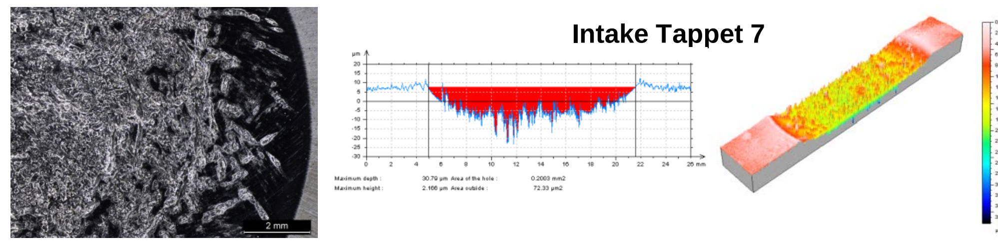
Intake Tappet 5



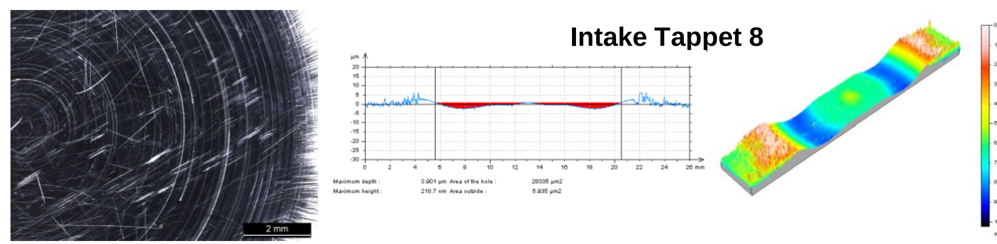
Intake Tappet 6



Intake Tappet 7

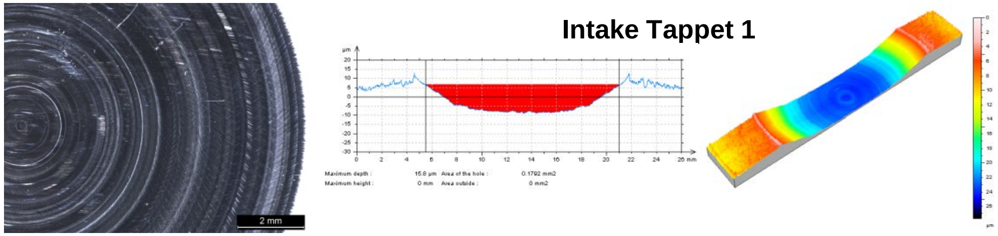


Intake Tappet 8

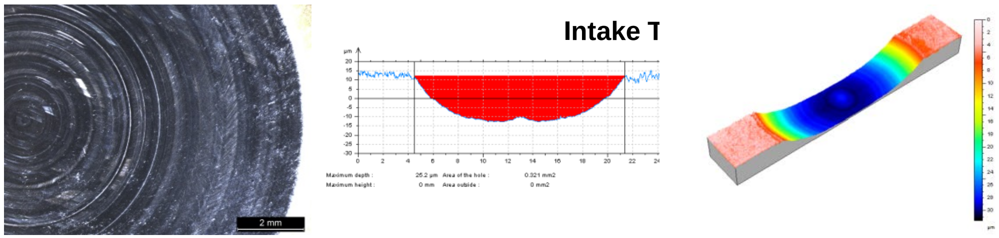


Tappets Analyses: Valid test

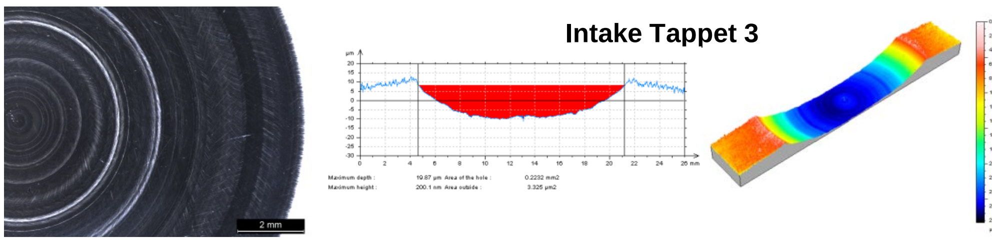
Intake Tappet 1



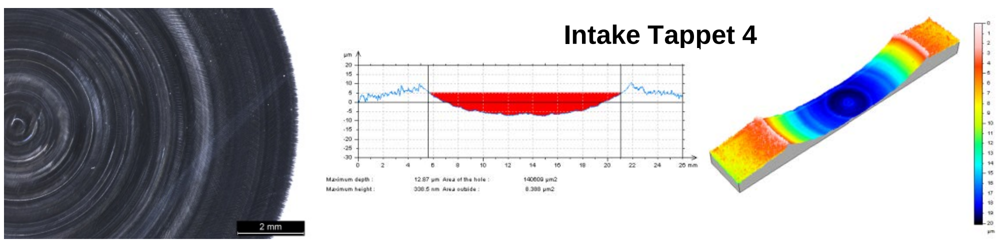
Intake T



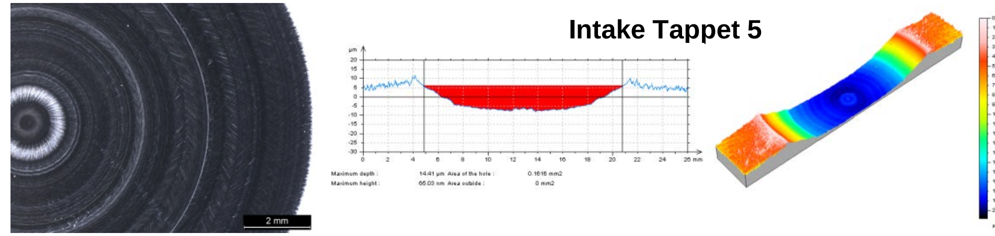
Intake Tappet 3



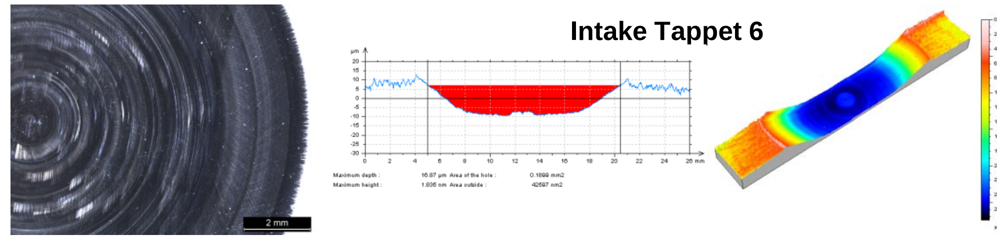
Intake Tappet 4



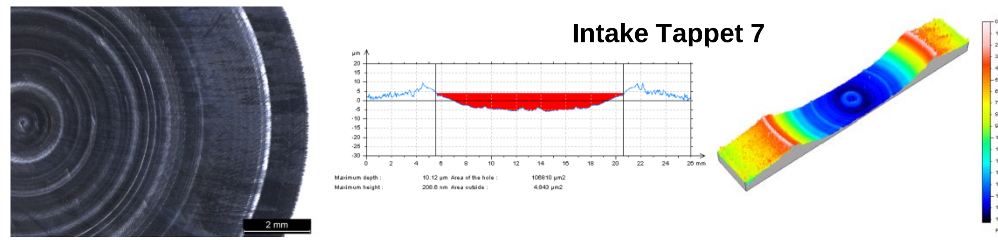
Intake Tappet 5



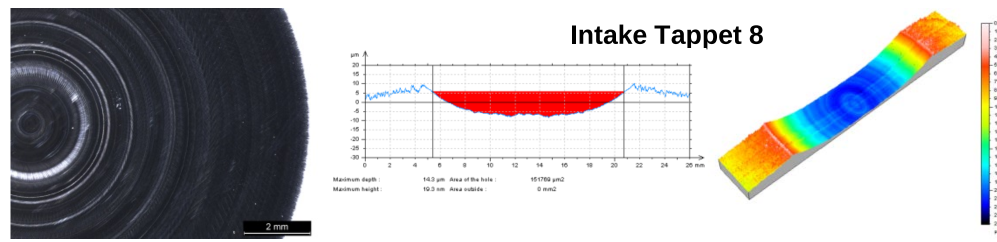
Intake Tappet 6



Intake Tappet 7



Intake Tappet 8



Tappet Wear: Integrated Shim

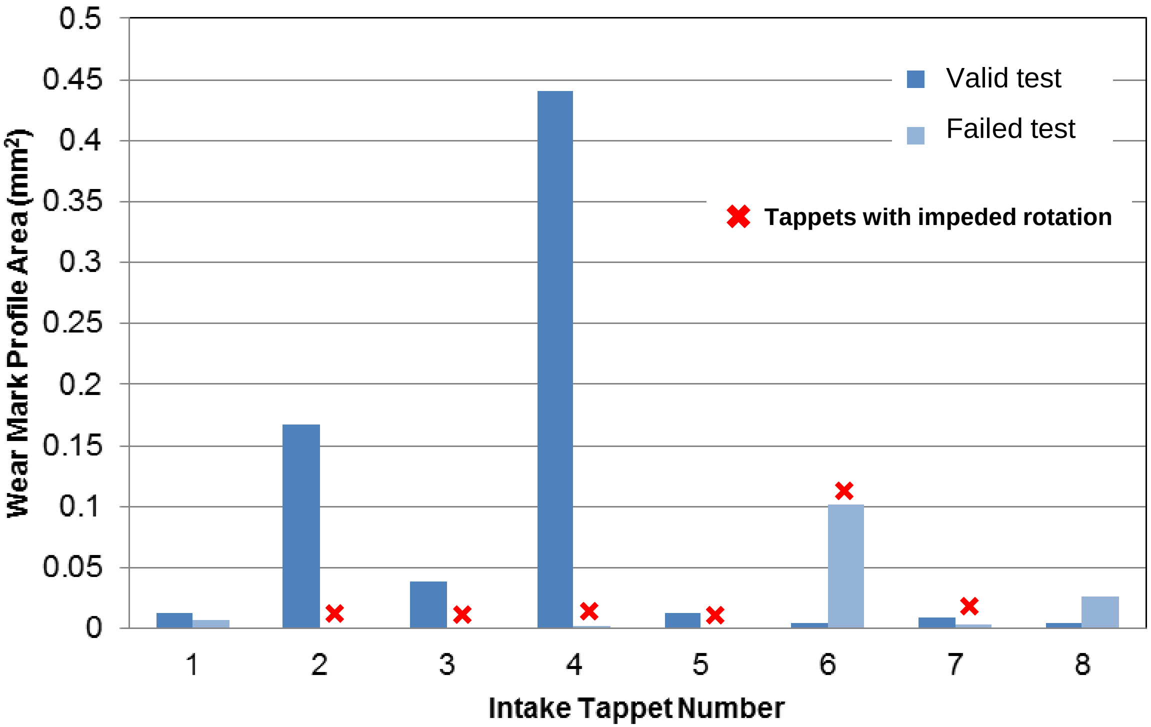
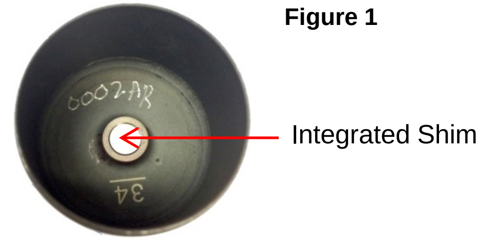


Figure 1



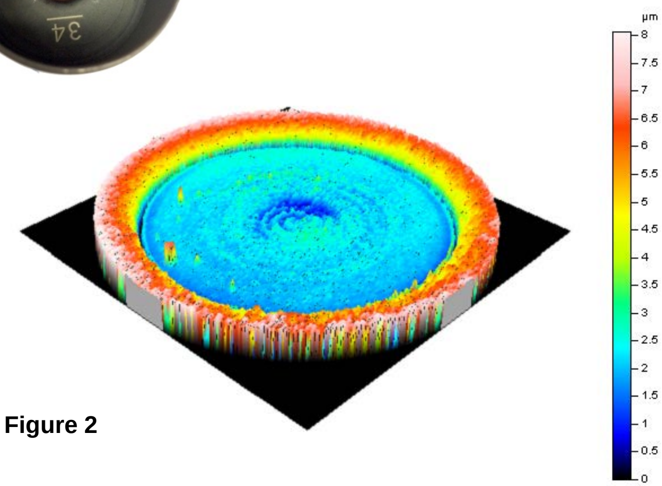


Figure 2

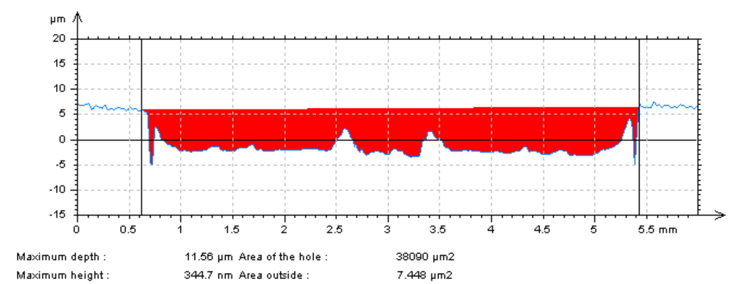
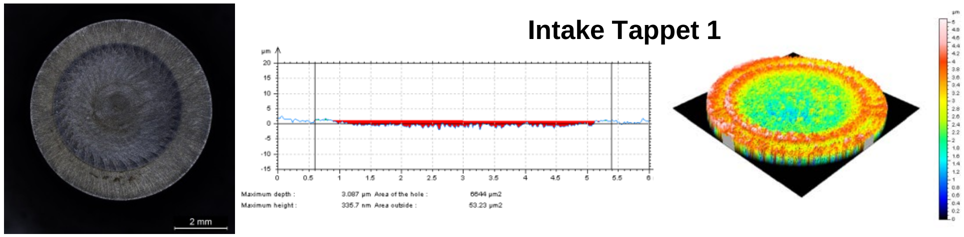
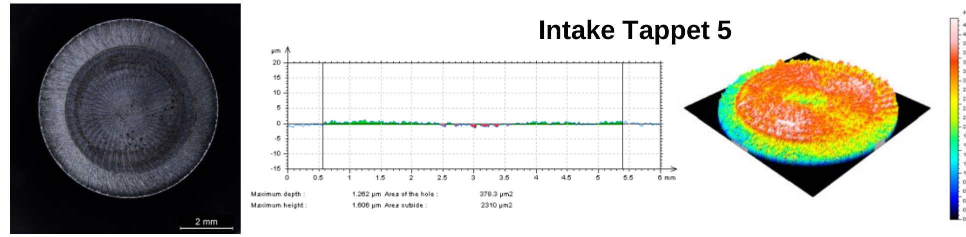
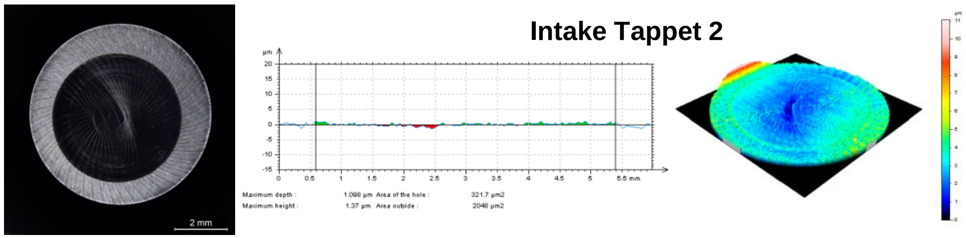


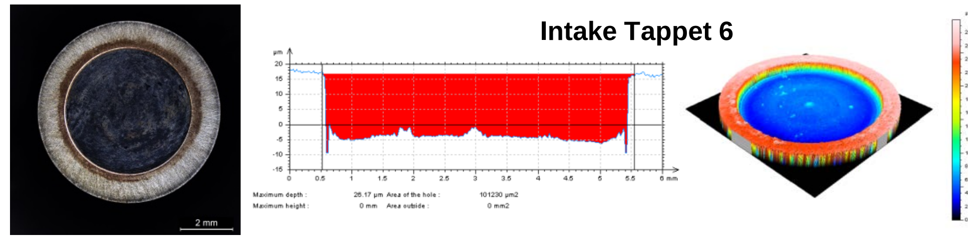
Figure 3

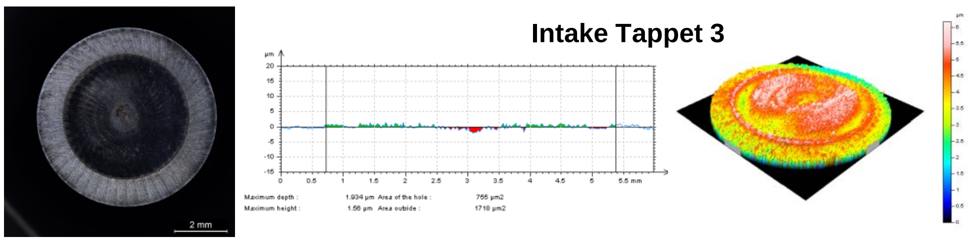
Tappets Analyses: Failed Cam Test

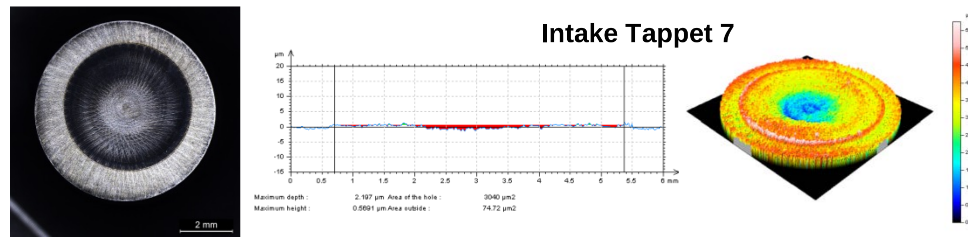


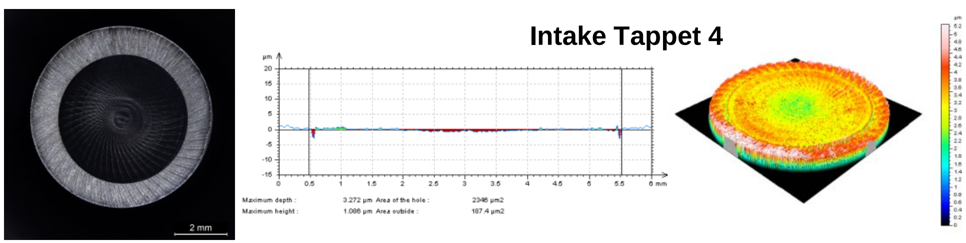


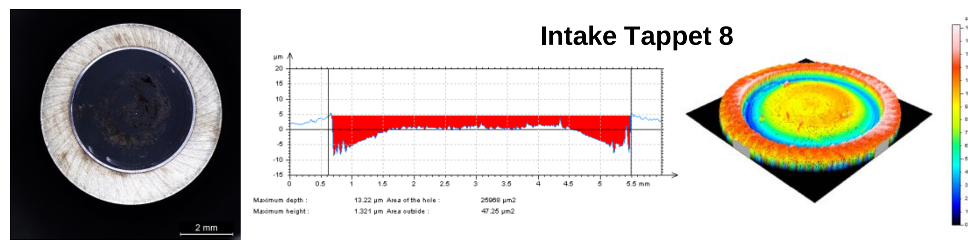






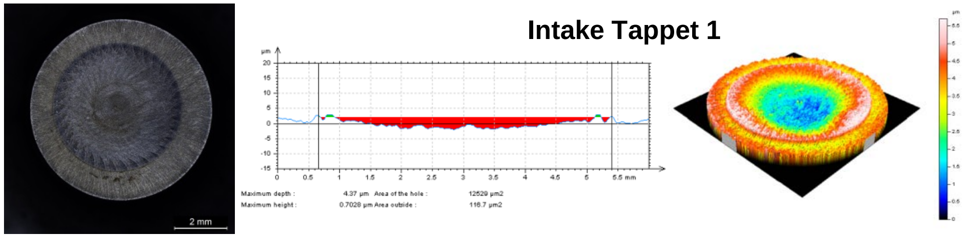




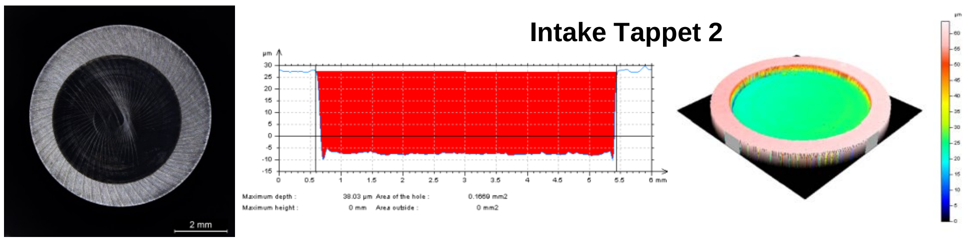


Tappets Analyses: Valid test

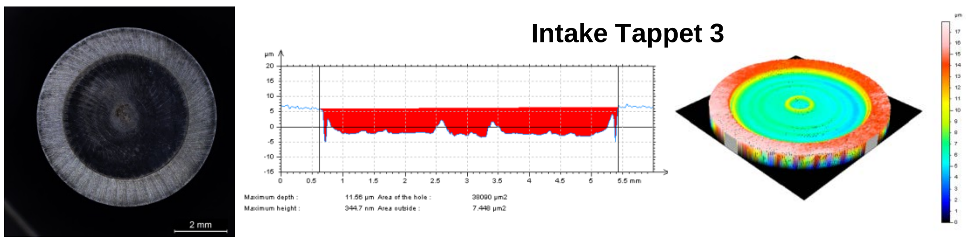
Intake Tappet 1



Intake Tappet 2



Intake Tappet 3



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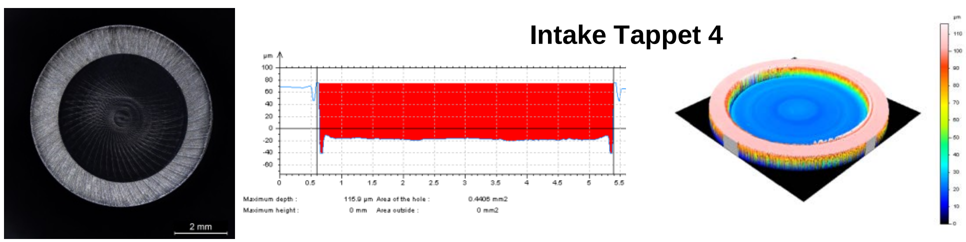
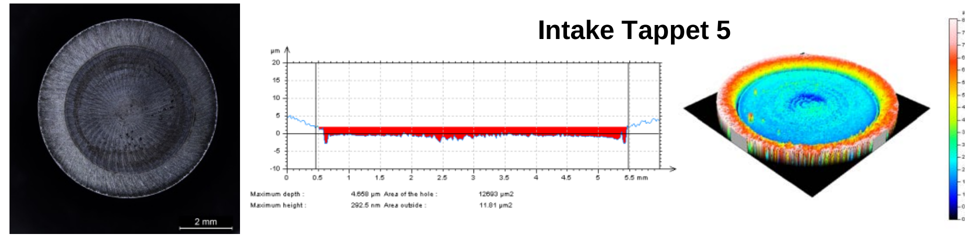
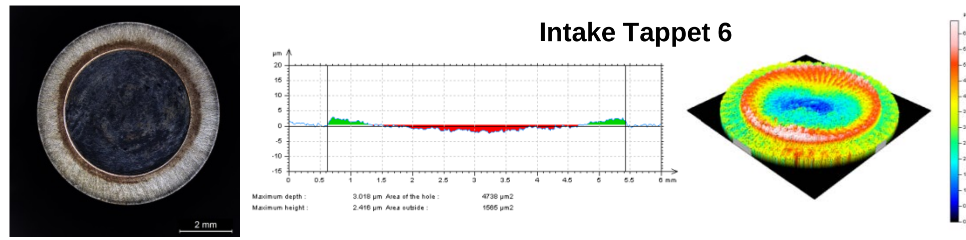


Intake Tappet 5



Intake Tappet 6



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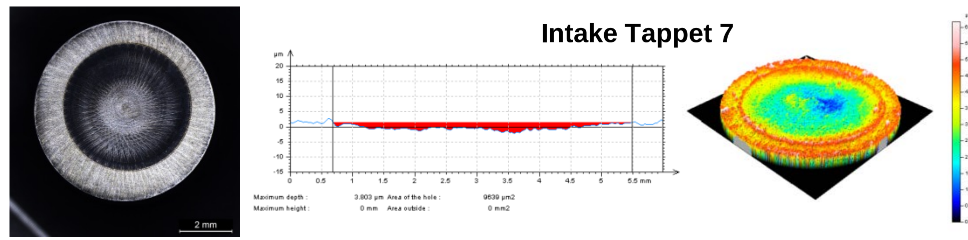
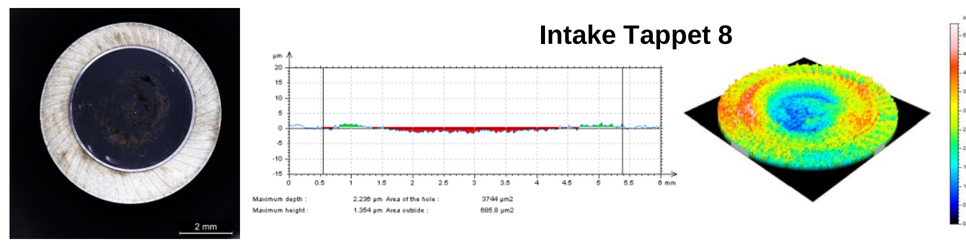


Intake Tappet 8



Possible causes of stopping of tappet rotation

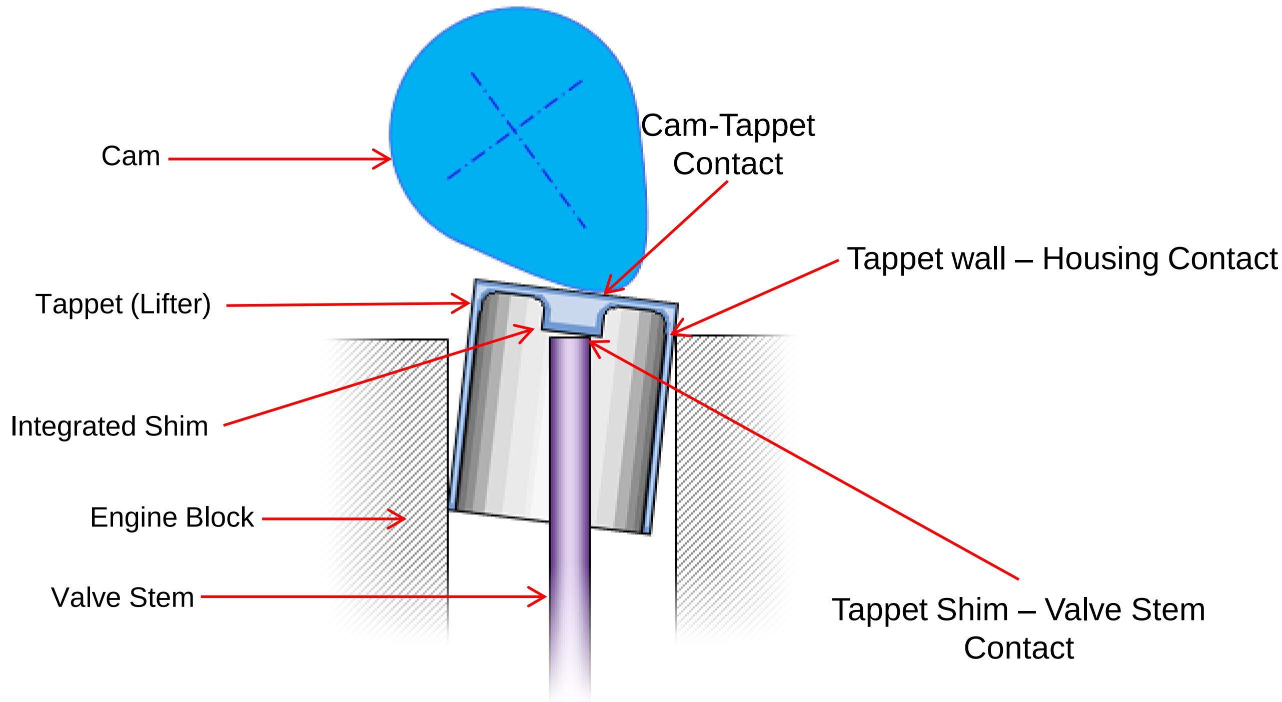
- The unusually severe wear observed in certain tests is unlikely to be caused by manufacturing or material inconsistencies in the valvetrain components (i.e. cams and tappets).
- Inadequate rotation of tappets appears to be the likely cause of severe cam wear in the tests where this phenomenon was observed. Inadequate or total stopping of the rotation of tappets changes the nature of the cam-tappet contact and tribosystem where the normal sliding/rolling type of contact (when tappet rotates consistently during operation) changes into a more severe pure sliding type of contact resulting much higher wear rates. As the cam surface is softer compared to the tappet surface, most of the wear occurs on the cam nose.
- Possible causes of stopping of tappet rotation in all scenarios include:

1. Formation of excessive amounts of deposits on the tappet walls that could cause sticking of the tappet to the housing walls (block) ➔ This can be ruled out as no deposits were observed to have formed on tappet walls.
2. Excessive valve spring compression increasing the contact pressure between the valve stem end and the circular shim underneath the tappet ➔ Currently under investigation by the engine lab.
3. Reduced traction between the cam nose and the tappet in the test engine due to:
    a) Geometrical modification of the cams in the test engine in comparison to the production version cams ➔ Highly unlikely as this type of failure has also been reported in test where production cams, rather than test cams, were used.
    b) Engine oils additives, e.g. friction modifiers ➔ Also highly unlikely as the failure was observed in oils with a consistent history of passing this test.
4. Engine block distortions: These can be caused by incorrect assembly of parts and/or thermal cycles.

Continued (see next page)

Possible causes of stopping of tappet rotation

5. Tilting of the tappet: Due to issues such as excessive wear of the bore walls of the tappet housing in the engine block or certain distortions in the engine block, the tappet may become tilted and stuck inside its housing preventing its rotation. This is schematically shown on next page.



Attachment 9

Sequence IV Surveillance Panel
October 27, 2015
9:00AM – 12:00PM
USCAR
Southfield, MI

Motions and Action Items
As Recorded at the Meeting by Bill Buscher

1. Action Item – Test Monitoring Center to survey the Sequence IVA test labs on the total quantity of both new and used Sequence IVA test engines and cylinder heads on hand. Survey to include a response on the total number of new test engines and cylinder heads on hand and the total number of used test engines and cylinder heads on hand. The survey to also include the total number of runs available from the new engines and cylinder heads and the total number of runs available from the used engines and cylinder heads, based on 48 runs per engine and 24 runs per cylinder head.

2. Action Item – Sequence IVB test development team to confirm the offset of the camshaft lobe to the lifter for Sequence IVB test engine.

3. Action Item – Toyota to review SwRI's "Effect of Valve Springs on Lifter Rotation in Sequence IVB" presentation and consult with their valve-train engineers.

4. Action Item – Toyota to schedule a follow-up conference call for 8:00pm Eastern Time this evening, 10/27/15, to discuss SwRI's "Effect of Valve Springs on Lifter Rotation in Sequence IVB" presentation with Hirano-san and the entire Sequence IV Surveillance Panel.