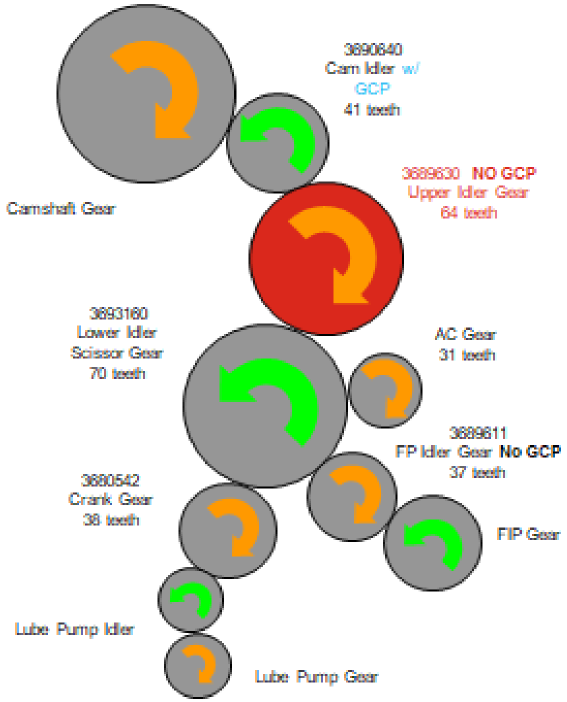
JTC Engineering Investigation

Upper Idler Gear Idler Shaft Expanding from Martensite Formation

By: Jessica Nicholson

Date Opened: 09/24/2021

Date Closed: ____



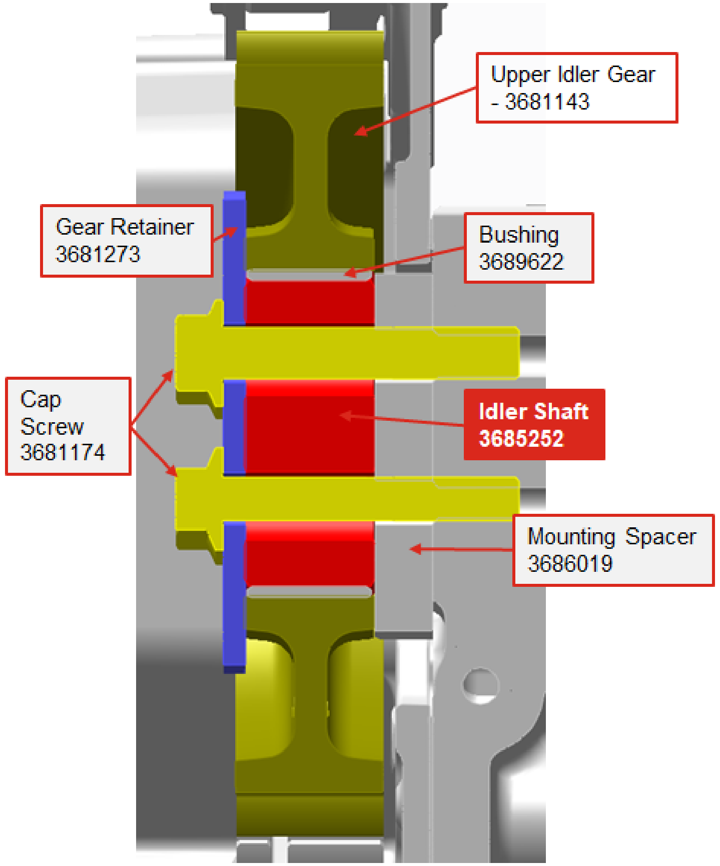
System Background

= Censored for confidentiality

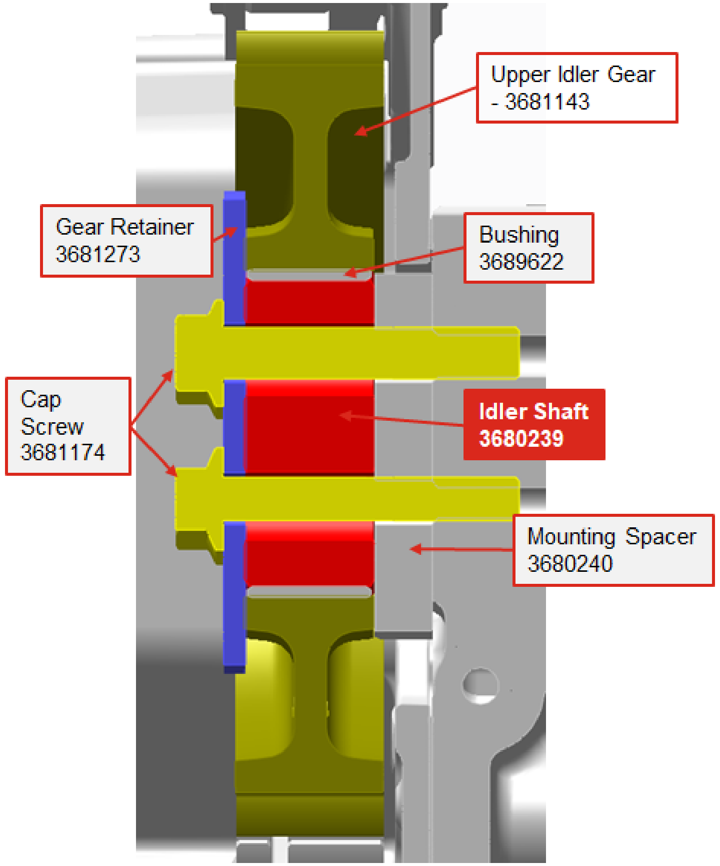
Single-Cam vs Dual-Cam Upper Idler Gear

- Current single-cam engines and older dual-cam engines have similar UIG systems
- Single-cam system
  - Idler shaft: 3685252
  - Mounting spacer: 3686019
  - Assembly: bb 1958
- Dual-cam system
  - Idler shaft: 3680239
  - Mounting spacer: 3680239
  - Assembly: bb 1902
- All other parts are common

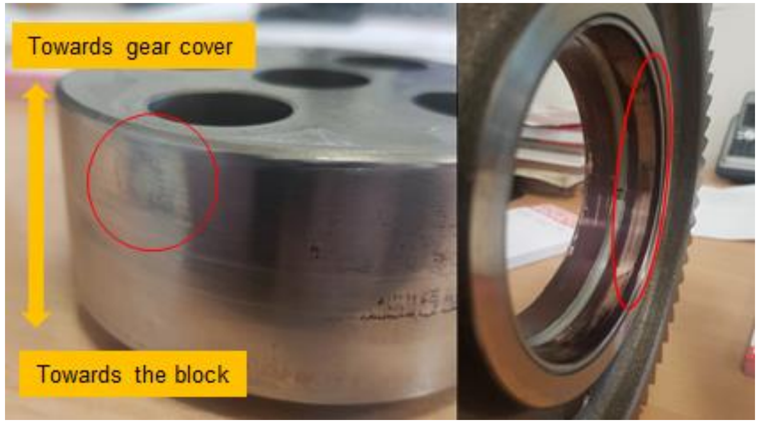
Single-Cam System



Dual-Cam System



Failing Component and Effects

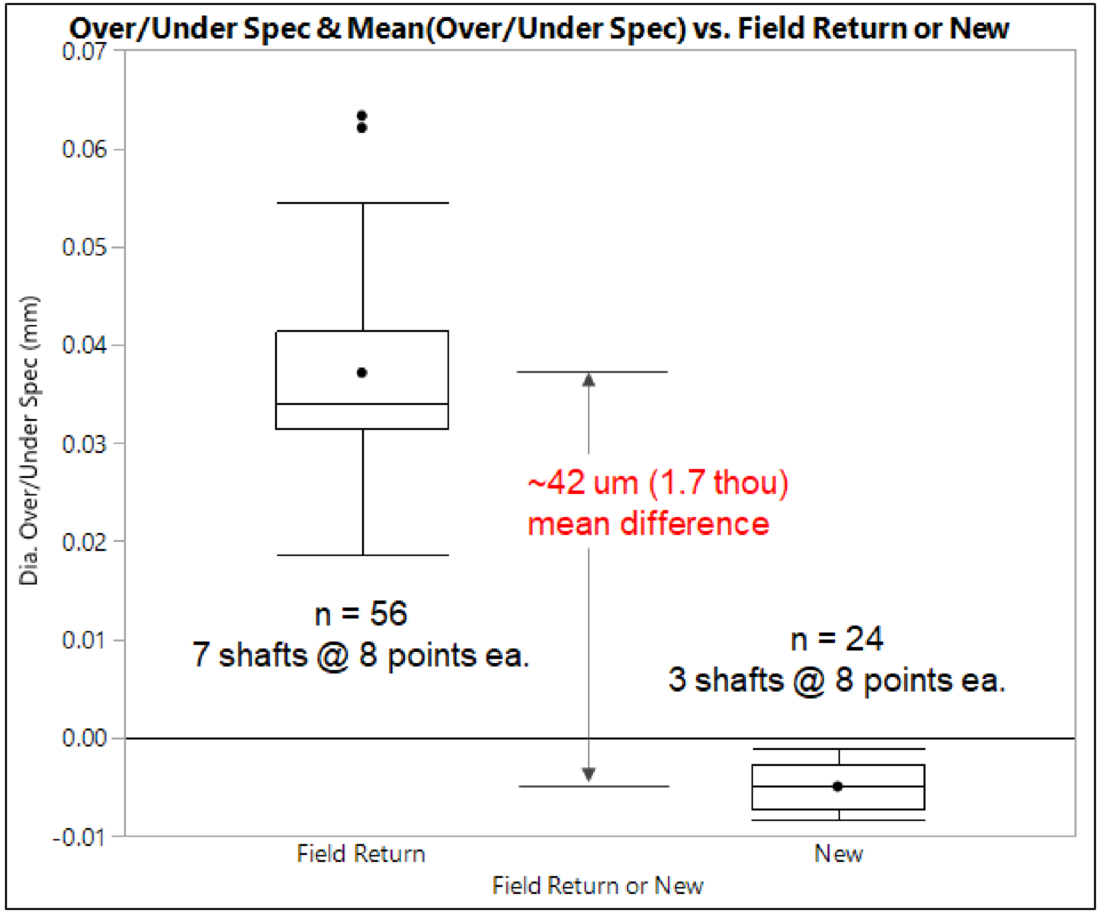


- **UIG idler shaft fails**
- Retained austenite within idler shaft transitions to martensite over time when preload is applied to bolts
- Effects of failure
  - Martensite formation causes material expansion, diameter increases
  - Clearance between idler shaft and bushing narrows
  - Hydrostatic oil film narrows and eventually closes
  - Lack of oil film causes system failure

- Failure occurred in both single and dual-cam systems until a solution was implemented for single-cam systems
  - Heat treatment procedure altered to decrease retained austenite, reduce failure

Single-Cam Idler Shaft Failure Before Solution

- Chart of new vs returned single-cam idler shaft diameters
- Before heat treatment change, returned idler shafts had a greater measured diameter than new parts
- Compare these results to diameter measurements of new single-cam idler shafts that have been in service for a significant time
    - Smaller diameter growth and fewer field returns expected



Claims Research

Purpose and Assumptions

- Conduct claims research for this idler shaft expansion failure in dual-cam configurations to determine need for a solution in dual-cam systems as well
- Any dual-cam system changes would be for service only, production ended
- Evaluate the RPH and cost of repeated failures in this system
    - A solution would only prevent repeated failures
- Failure due to idler shaft expansion may be reported as a failure of multiple UIG components
    - Failure codes: BKIS, BKIG, BKIP, BKIQ, BKIB, BKMI
- Compare dual-cam claims results to single-cam system for same failure
    - Single-cam system idler shaft heat treatment altered to prevent failure
    - Number of claims / failure rate of dual-cam system should become similar to single-cam system if idler shaft issue is addressed

RPH and CPE Plots – Dual Cam System

[redacted]

- Build volume: 377,503, Claims: [redacted], Average RPH = [redacted]
  - BKIS: [redacted], BKIG: [redacted], BKIP: [redacted], BKIB: [redacted], BKIQ: [redacted], BKMI: [redacted]
- Average replacement cost = $8,275.55, Average CPE = $1.95

RPH and CPE Plots – Single Cam System

[redacted]

- Build volume: 764,311, Claims: [redacted], Average RPH = [redacted]
  - BKIS: [redacted], BKIG: [redacted], BKIP: [redacted], BKIB: [redacted], BKIQ: [redacted], BKMI: [redacted]
- Average replacement cost = $13,675.51, Average CPE = $2.49

Dual-Cam Plot Results and Single-Cam Initial Results

- Sharp increase in dual-cam failure rate in 2019, CPE from newest engines higher than average
  - Lower build volume
  - Design changes
- Highest failure rate trends
  - By configuration, D103006BX03 ([redacted])
  - By location, United States ([redacted]), Australia ([redacted])
- Based on single-cam results, a dual-cam solution would likely yield a lower RPH in dual-cam systems, however:
  - The single-cam idler shaft heat treatment change was implemented 4/12/2021
  - There is not enough claims data past this date to evaluate fix effectiveness and compare to current dual-cam claims

Dual-Cam System Results

- Failures significantly increase in the single-cam system once bolt preload increase is implemented
- We cannot yet see the effect the single-cam solution has on its failure rate
  - However, we can reasonably assume that the reduction in retained austenite from heat treatment changes reduces martensite growth and reduces diameter growth and failure due to operation
- A similar solution in the dual-cam system for service should reduce failure

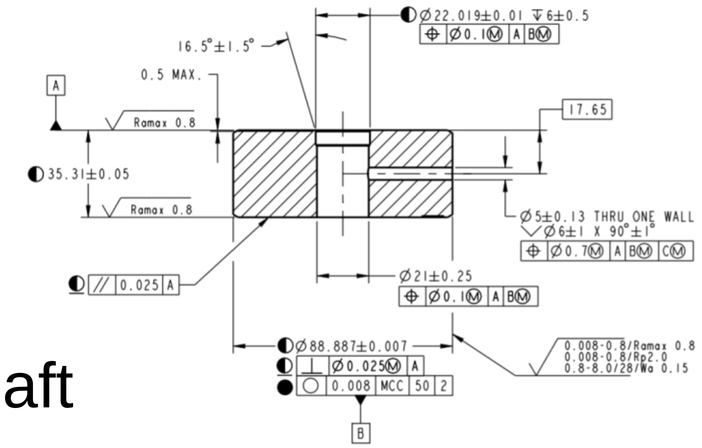
Proposed Solution

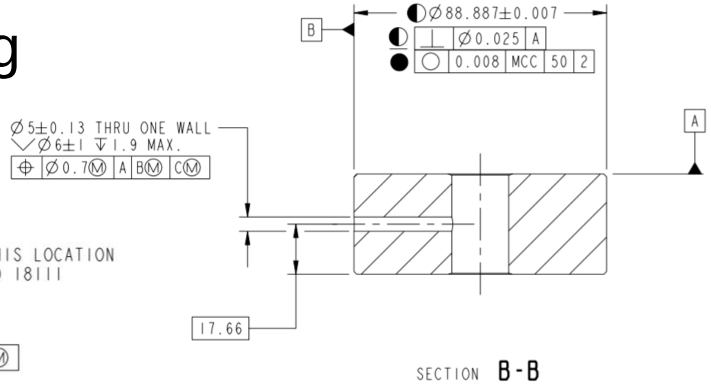
Solution and Justification

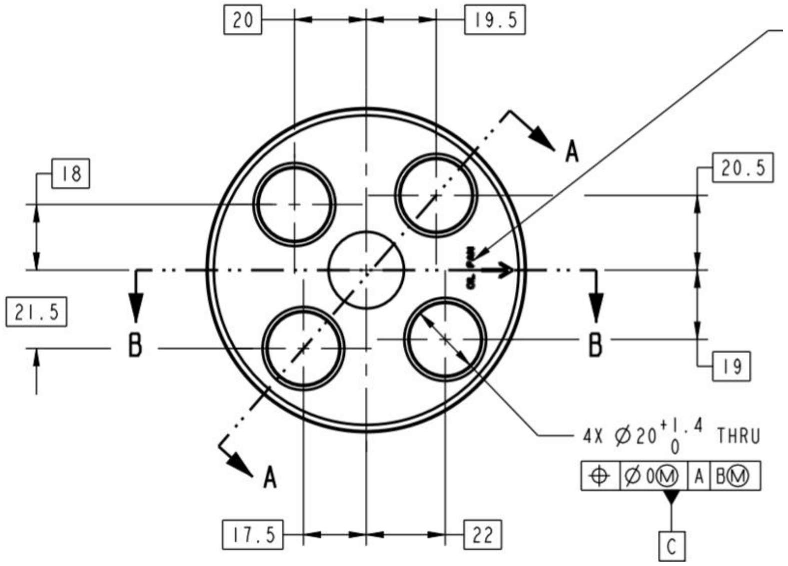
- Prevent the dual-cam system UIG idler shafts from generating martensite during operation from retained austenite
- **Replace dual-cam idler shaft** with the single-cam system UIG idler shaft
  - Single-cam system UIG idler shaft does not experience the same issue due to previous heat treatment changes
  - Both UIG systems are similar, with all parts common except for idler shaft and mounting spacer
- Opportunity to commonize the UIG idler shaft for both systems
- May have to redesign single-cam system idler shaft or dual-cam system components to accommodate single-cam system idler shaft

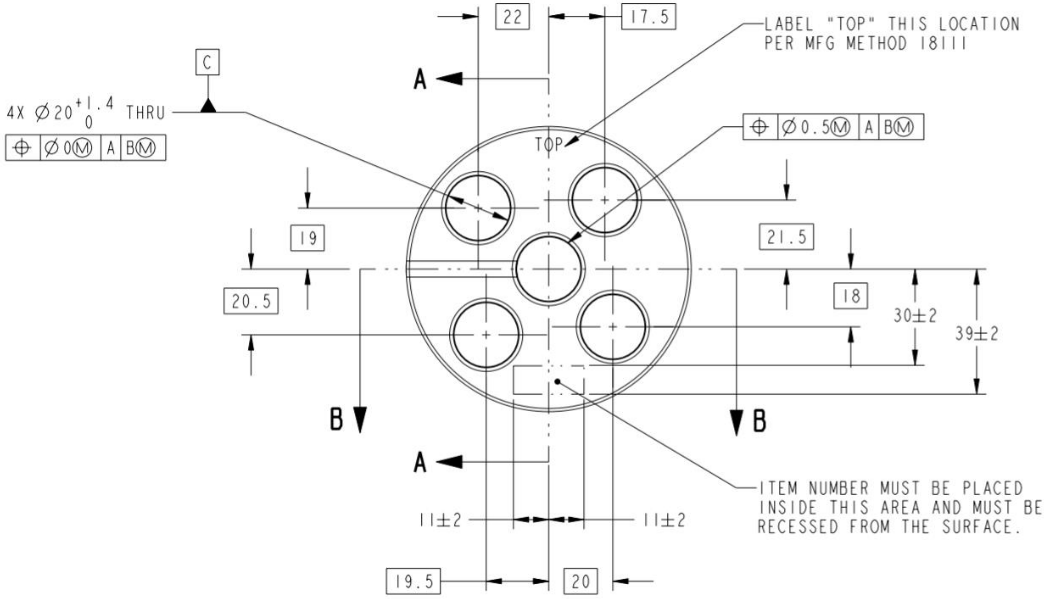
Fit Validation

- Key variations between single vs dual-cam UIG idler shaft
  - Center hole diameter larger by 1 mm
  - Center hole structure, counterbore present for dowel ring
  - No chamfer on center hole



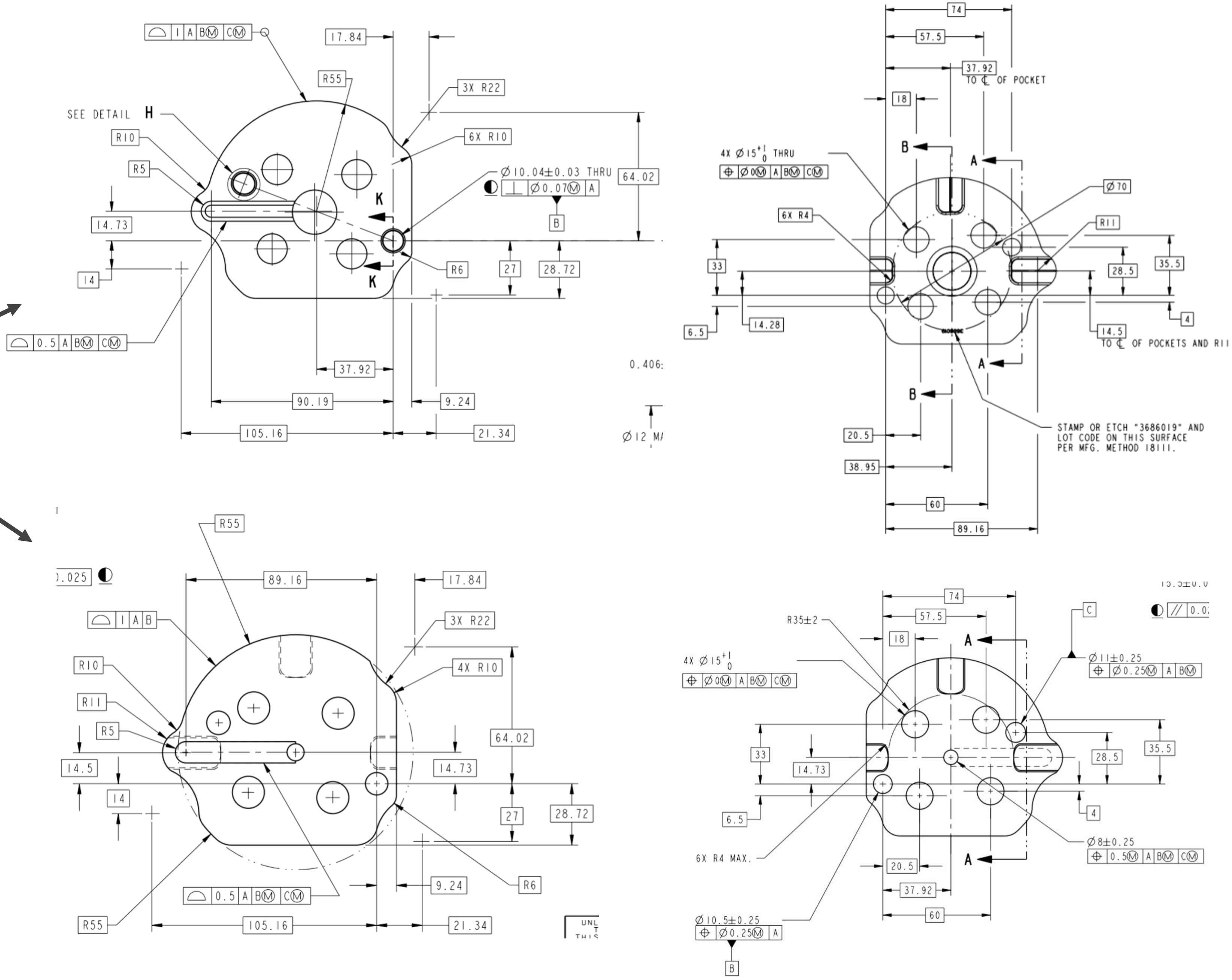




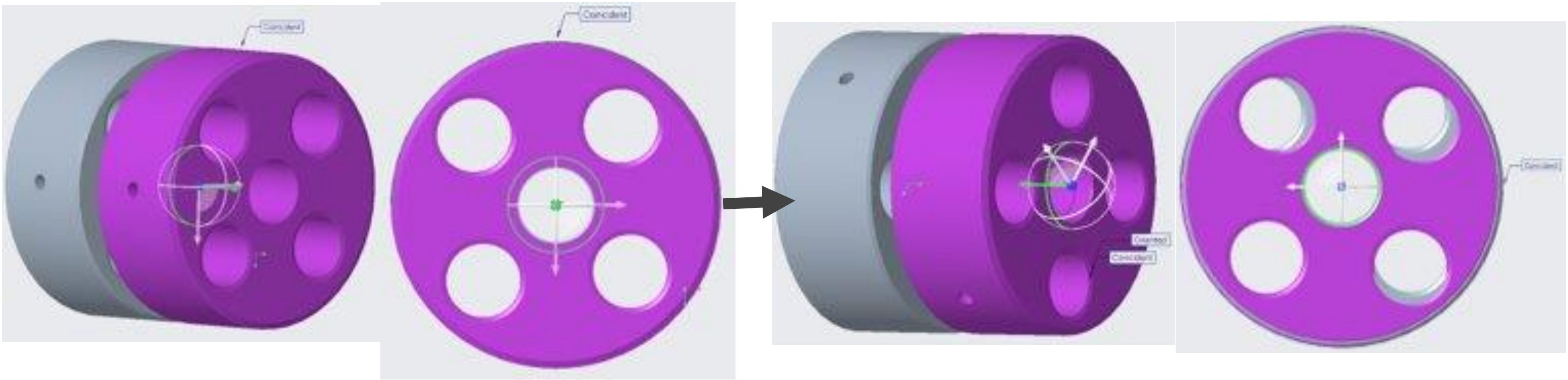


Fit Validation

- Key variations between single-cam vs dual-cam UIG mounting spacer
  - Relative positions of all holes the same, except for all holes to center hole
  - Length of oil feed differs by 1 mm

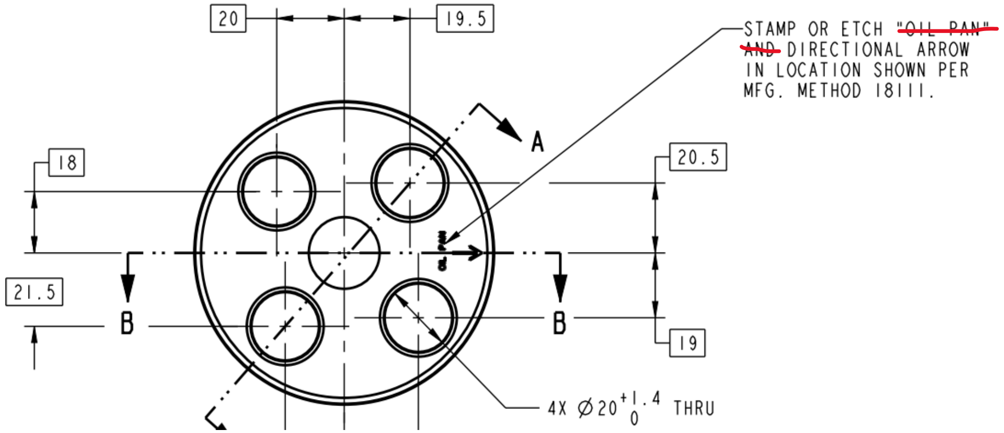


Fit Validation



- System differences
  - Single-cam system idler shaft connected rigidly to block with press-fit dowel pin
  - Dual-cam system idler shaft and mounting spacer not rigidly connected to block
  - Dual-cam idler shaft cannot be rigidly connected, needs to adjust for lash, so ensure single-cam idler shaft is not fitted with a dowel pin for this application
- No idler shaft design differences are significant to its fit within system
- Single-cam idler shaft can therefore replace current dual-cam idler shaft
  - No design changes necessary
  - Compatible with current dual-cam mounting spacer
  - Rotate single-cam idler shaft 90 degrees clockwise to fit to dual-cam system
- No need to replace mounting spacer
- All other components are common between systems

Service Implementation



- Change labeling on single-cam idler shaft
  - Remove "OIL PAN" and leave the arrow
  - Eliminates service confusion as this idler shaft will be oriented differently on dual-cam systems
- Implement one of these part availability changes in order to make the single-cam idler shaft saleable as an individual part
  - Switch assembly to production-only to make each part saleable in service
  - Make the individual mounting spacer part non-saleable to justify the assembly
- Submit TSB to change instructions and labeling on service manual diagrams
  - Ensure single-cam idler shaft is ordered as needed for dual-cam service
  - Specify orientation in single and dual-cam system manuals

Solution Validation

Potential Failure Modes

- Remaining austenite may still form martensite, causing idler shaft expansion beyond dimensional allowance – heat treatment change insufficient
- Dowel ring installed in idler shaft during service although it must not for the dual-cam system
  - Dual-cam mounting spacer has no room for a dowel ring, no concern
- Idler shaft installed in incorrect orientation for the dual-cam system
  - Idler shaft labeling and service manuals altered to reflect correct orientation

Single-Cam Idler Shaft Change

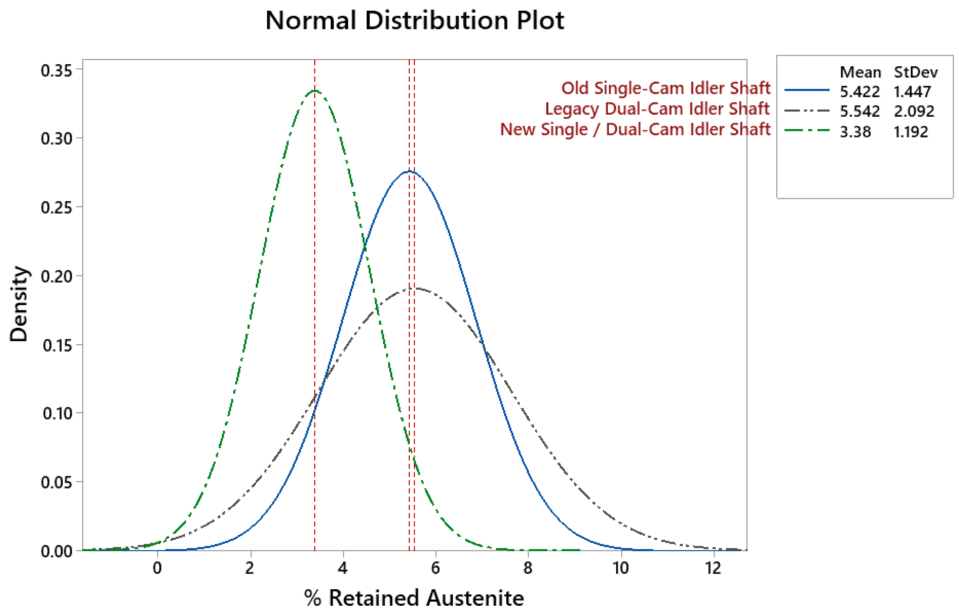
- Claims data is insufficient to determine effectiveness of single-cam change
- Confirm that the single-cam idler shaft heat treatment change is effective
  - Single-cam idler shaft is now baked at 400 F for 90 minutes rather than 350 F
  - Must experience less radial expansion than previous design and current dual-cam idler shaft
- Comparative tests performed on new vs original single-cam idler shaft
  - Measured diameter of new vs returned idler shafts + heat treatment differences
  - Retained austenite levels of new vs returned + heat treatment differences
  - Comparative test can determine effective rate to predict failure prevention
- Test results detailed in CTR 4120261

CTR 4120261 Results

- All 6 returned failed samples found to have diameters above max spec
- Retained austenite levels measured in new and failed samples of original idler shaft
  - High retained austenite levels in new samples
  - Lower retained austenite in failed samples, expected with martensite formation
- Bolt preload changes have minimal effect on idler shaft expansion
- New heat treatment process trial – 400 F, 90 mins vs original 350 F, 90 mins
  - Retained austenite from new process is an average of 40% lower
  - Hardness drops an average of 8%, still within spec
- Effects of lower retained austenite
  - Additional extended heat test performed on both shafts – 400 F for 24 hours
  - Radial growth decreases about 19% for the 40% reduction in retained austenite

Dual-Cam System Solution Effective Rate

- Old single-cam idler shaft avg RA = 5.422% Std dev = 1.447
- Legacy dual-cam idler shaft avg RA = 5.542% Std dev = 2.092
- **New single-cam idler shaft** avg RA = 3.380% Std dev = 1.192
  - 37.7% reduction in retained austenite from old single-cam idler shaft
  - 39.0% reduction in retained austenite from current dual-cam idler shaft



- Since these retained austenite reduction rates are approximately the same, we can assume about the same **19% reduction in radial growth** from the dual-cam idler shaft
- Radial growth reduction should correlate to reduction in failures

Cost Justification

Service Volume Trends

- Approximate current dual-cam idler shaft annual service volume = 19
- Approximate current single-cam idler shaft annual service volume = 115
- New single-cam idler shaft service volume = dual + single = 134

[redacted]

*No clear trends, used average claims per year

Claims Cost Savings

- Approximated current single-cam savings:
  - RPH = [redacted], CPE = [redacted]
  - Approximate annual volume = 54,594
  - Annual cost due to claims = $135,939.06
  - With a 19% reduction in failure, annual savings = $25,828.42
- Projected dual-cam savings after change:
  - RPH = [redacted], CPE = $1.95, average service cost = $8,275.55
  - Production will cease, so savings will be from prevented repeat services
  - Total repeat services = 46, annual repeat services = 3.3
  - Approximate annual cost of repeat services = $27,309.31
  - With a 19% reduction in failure, annual savings = **$5,188.77**
- Total annual savings = **$31,017.19**

Fixed Costs, Claims Cost, and Break-Even Point

- No piece price change due to labeling modification
- Fixed costs and production lead-time
  - Idler shaft labeling modification tooling cost = [redacted]
  - Lead time unknown
- Break-even point = **0.607 years**
  - Considering annual service savings vs fixed tooling cost

My Recommendation

My Recommendation

- Create CTR -> ER to implement labeling change for single-cam idler shaft
- Make single-cam idler shaft saleable in service as per slide #17
- Submit TSB to alter service manuals for dual-cam systems

After service implementation:
- Monitor single-cam claims to ensure initial heat treatment change is effective
- Monitor dual-cam claims to ensure idler shaft replacement creates fewer repeat claims
    - Should reflect solution effective rate calculation, may not be exactly correlated to radial growth decrease


Cummins