BOUNDARY ENGINEERING

Machining Division

Relief Valve Failure Analysis

STUART DUNHAM

AND

TRAVIS ROSENBARGER

2/23/2010

Document Release:

This document as presented on February 23, 2010 is the finding of the review panel at Boundary Engineering Machining Division. We certify that the statements in this report have been made objectively and are only based on factual evidence. We do not assert or indicate any directly responsible party within this document.

Failure Analysis Tampering Release:

We certify that the oil pump we received from the customer has not been tampered with in any way since receiving the item. This item has been left on a shelf in the machine shop since it was received and initially validated. The humidity and temperature that the oil pump was stored in since we received it are those conditions found in an indoor heated facility.

Experience Release:

The failure analysis provided in this report including, the pictures, the measurements, the hardness specifications, and the conclusion is the work of Stuart Dunham. Stuart Dunham has 31 years of experience in failure analysis and mechanical design. Stuart's primary experience is from evaluating machine tool spindle bearing failure. He has direct experience with lubrication system failure, debris failure, thermal failure, and failure from improper geometry. Boundary Engineering believes Stuart's opinions are valid because of his experience in this type of failure. Boundary Engineering believes his previous experience gives him the expertise necessary to create an opinion on why the relief valve failed.

I Travis Rosenbarger, Sole Manager of Boundary Engineering LLC, certify that the above release statements are valid for this document "Failure Analysis of Relief Valve" submitted February 23, 2010.

Travis Rosenbarger

Digitally signed by Travis Rosenbarger
DN: cn=Travis Rosenbarger, o=Boundary Engineering, ou=Owner, email=travisr@boundaryengineering.com, c=US
Date: 2010.02.24 14:45:26 -05'00'

Relief Valve Failure Analysis

Contents

IN THIS REPORT:

This report displays information on the failure of a Boundary Engineering oil pump assembly's relief valve system. This document contains pictures, specifications, and dimensions of the damaged pump and an analysis is provided.

Oil Pump Failure Analysis

Overview of Failure

IN THIS SECTION:

- Ø Timeline of Failure
- Ø Symptoms of Failure
- Ø Recommendations to Fix Failure
- Ø Outcome of Evaluations
- Ø Outcome of Incident

Timeline of Failure:

9/15/2009

The product is purchased by customer.

11/2/2009

The customer files a complaint of high oil pressure in his engine. He suspects the oil pump.

The customer states that the pressure is extremely high. The engine has been run, and broken in. He reports that the pressure remains high until 170°F in oil temperature. Below 150°F oil temperature the oil pressure is beyond the capability of either the oil pressure gauge or the software to monitor. Customer also reports that the oil filter is deforming under pressure.

The customer is running 10W-30 Valvoline VR-1 when the oil filter was ejected off the block. Customer switched to Royal Purple 5W30 synthetic. The oil pressure behavior did not change.

The customer suggests that the relief valve may be functioning differently as temperature changes.

The customer supplied pictures of damage done to oil filter from the high oil pressure. These are attached in the appendix as item 1 and 2.

Charts of the customers datalogs are attached as item 3-6 in the appendix showing the relation of pressure to temperature.

November, 16, 2009

Customer provided details of clearances in the bottom end of the engine. The clearances were not any tighter then stock, and were in specification.

Customer provided cold start data directly from his data log software showing the oil warm-up characteristics. The general trend of the warm-up cycle includes high oil pressure at low temperature, eventually stabilizing at around 175°F water temperature.

The motor has been through several tests. The first test was performed by his mechanic. A chart of this warm-up is available in item 8 of the appendix.

Oil Type	Mobile 1 0W-20
Ambient Temperature	55°F
Oil pressure reading at startup	62 PSI
Pressure at idle after warm-up	22 PSI

The second test performed that afternoon. The chart of this warm-up is available in item 9 of the appendix.

Oil Type	0W-20
Ambient temp	60°F
Oil Pressure Reading at Startup	100+PSI
Mechanical gauge connected at startup	145-150 PSI
Pressure came down some after 10 Seconds	130-140 PSI
2000 RPM oil pressure	200 PSI
Pressure after warm-up complete.	20-30 PSI

Customer is really concerned about the level of these pressures. He suggests many possibilities. The conversation is available in the appendix as item 10.

The customer was sent an email stating that what we were seeing was either an intermittent blockage of the oil system or a relief valve failure. A copy of this is available in the appendix as item 11.

November, 27,2009

The customer is asked to return the pump so that we can evaluate it and see if a warranty is to be given. Customer was given the specification process for evaluating each pump. This document is provided as item 12.

December, 4, 2009

The customer informs Boundary Engineering pump was not returned yet. He says he will send the pump early next week.

December, 8, 2009

Boundary Engineering contacts customer to see if the pump has been returned yet. Customer replies he will ship the pump back by tomorrow December, 9, 2009.

December, 18, 2009

Boundary Engineering sends an email message telling customer that the pump cannot be replaced with a new one until the pump is sent back so that it can be evaluated.

December, 22, 2009

Boundary Engineering receives the pump from the customer. We begin our failure analysis.

Boundary Engineering issues an email covering the failure analysis. This analysis which was performed by Travis Rosenbarger with the help of Stuart Dunham, is attached in the appendix as item number 13. The failure analysis states that the failure was caused by debris or a housing problem.

Boundary Engineering issues a replacement pump.

Symptoms of relief valve part failure as recorded by the customer:

- The relief valve failure in this case creates a high pressure condition in the engine which can exceed 200 PSI.
- The failure of the relief valve to control pressure is removed when the vehicle goes to operating temperature.
- Viscosity does not reduce or increase the effect of the relief valve to control pressure.
- Relief valve returns to normal operation in a very snap like action.

Recommendation to repair the failure:

All other possible causes that both the customer and Boundary Engineering proposed have been evaluated. All solutions that did not involve removing the oil pump have been tried. None of these solutions fixed the problem. It is assumed that the failure can only be fixed by replacing the damaged pump. It is recommended that the oil pump be removed and returned to Boundary Engineering so that we can evaluate the pump.

Outcome of the evaluation:

The experts at Boundary Engineering who evaluated the pump suspect that foreign matter entered the oil pump assembly and damaged the relief valve. It is the opinion of Stuart Dunham that Boundary Engineering Machining Division was not at fault and could not have prevented the failure of this pump regardless of measures taken in the manufacturing process.

Outcome of the incident:

Despite the finding that Boundary Engineering was not at fault, the pump was replaced free of charge to the customer in an act of good will.

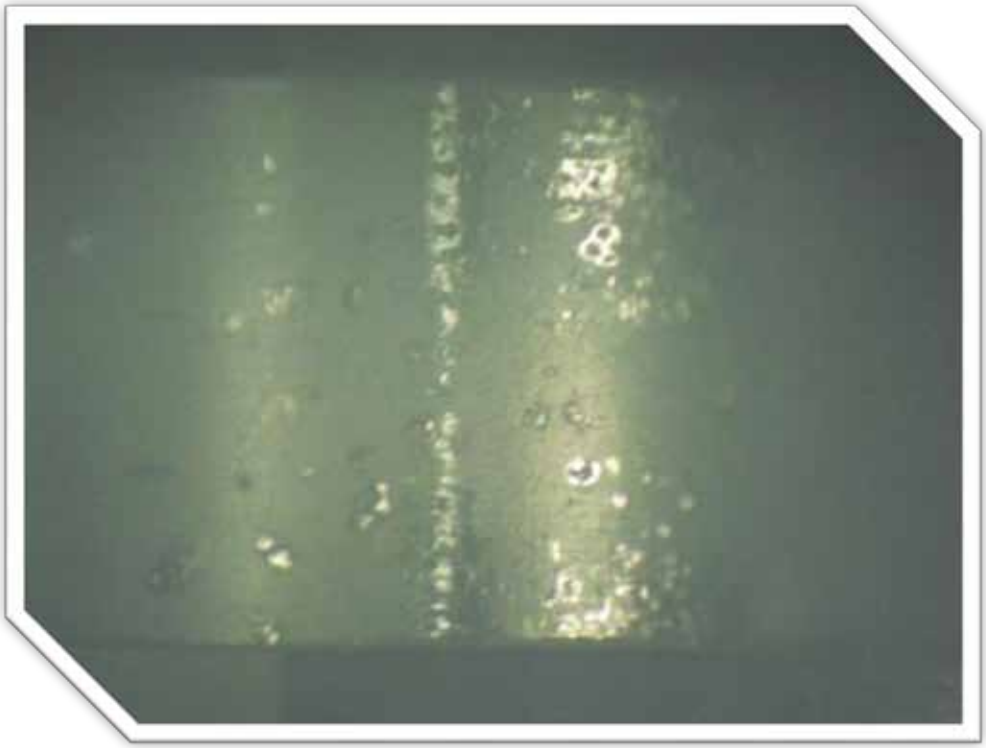
Oil Pump Failure Analysis

Inner Gear Details

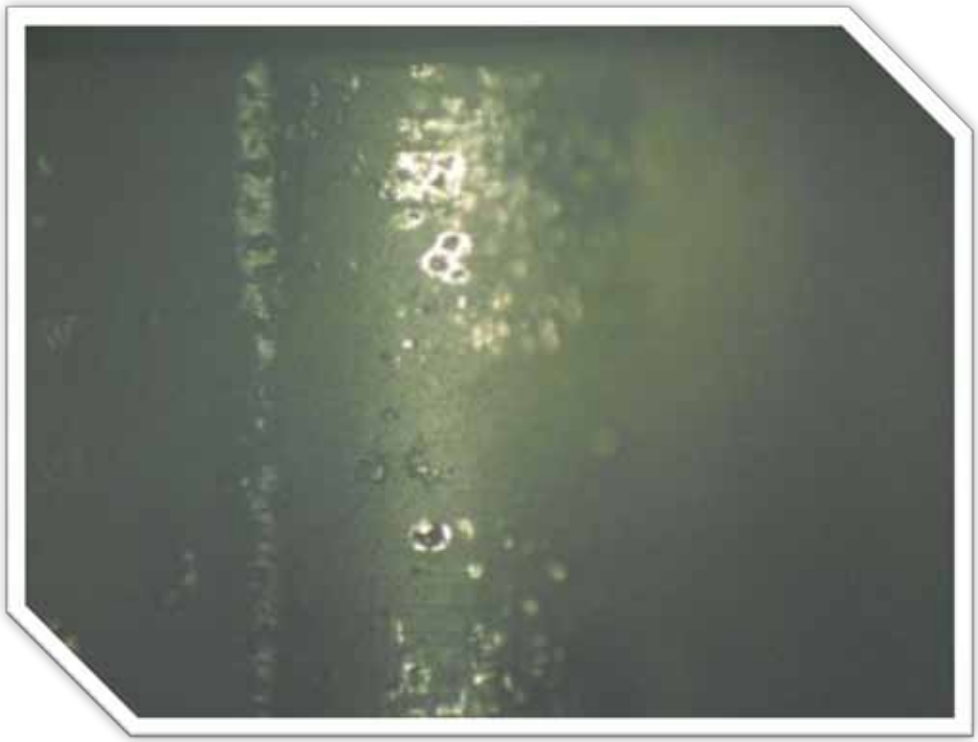
IN THIS SECTION:

- Ø Pictures of damage to inner gears
- Ø Reason for damage

Inner gear picture showing damage. Magnification 10X



Inner Gear Picture showing damage 2. Magnification 10X

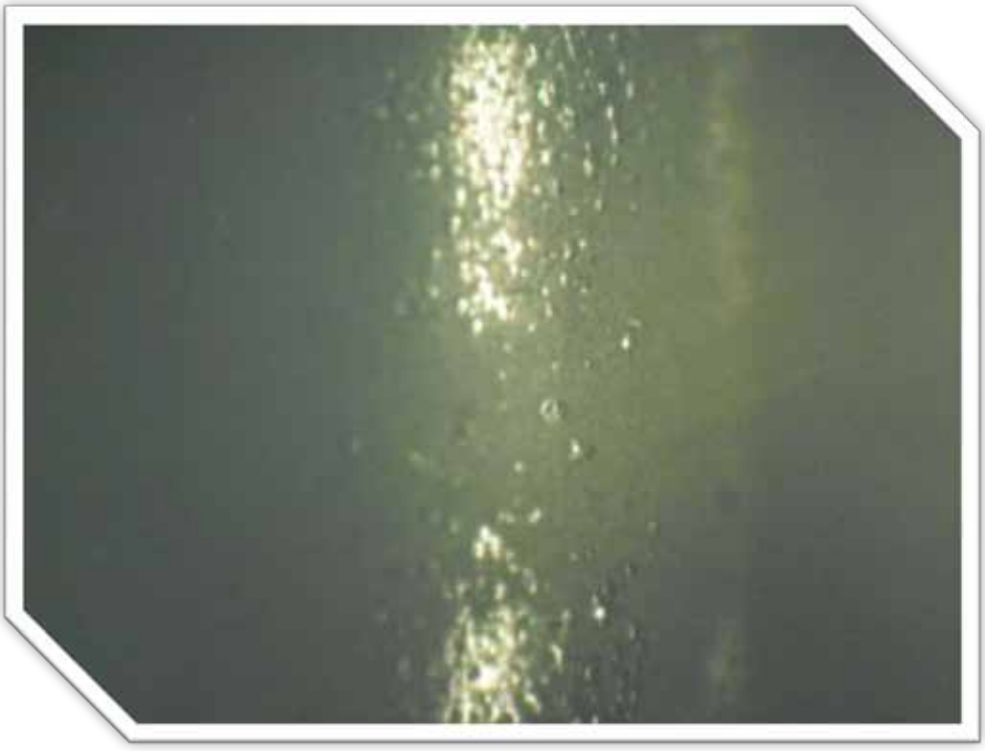


Inner gear picture showing damage 3. Magnification 10X

Inner gear picture showing damage 4. Magnification 10X

Inner gear picture showing damage 5. Magnification 10X

Inner gear picture showing damage 6. Magnification 10X



Inner gear picture showing damage 7. Magnification 10

Suspected reason for damage to inner gear:

The damage in the above photos on the inner gear is suspected to be caused by debris harder than Rockwell C-14 entering the pump. Pictures were taken using an optical comparator and a standard microscope, using a CCD device to obtain images from the Microscope.

Relief Valve Failure Analysis

Outer Gear Details

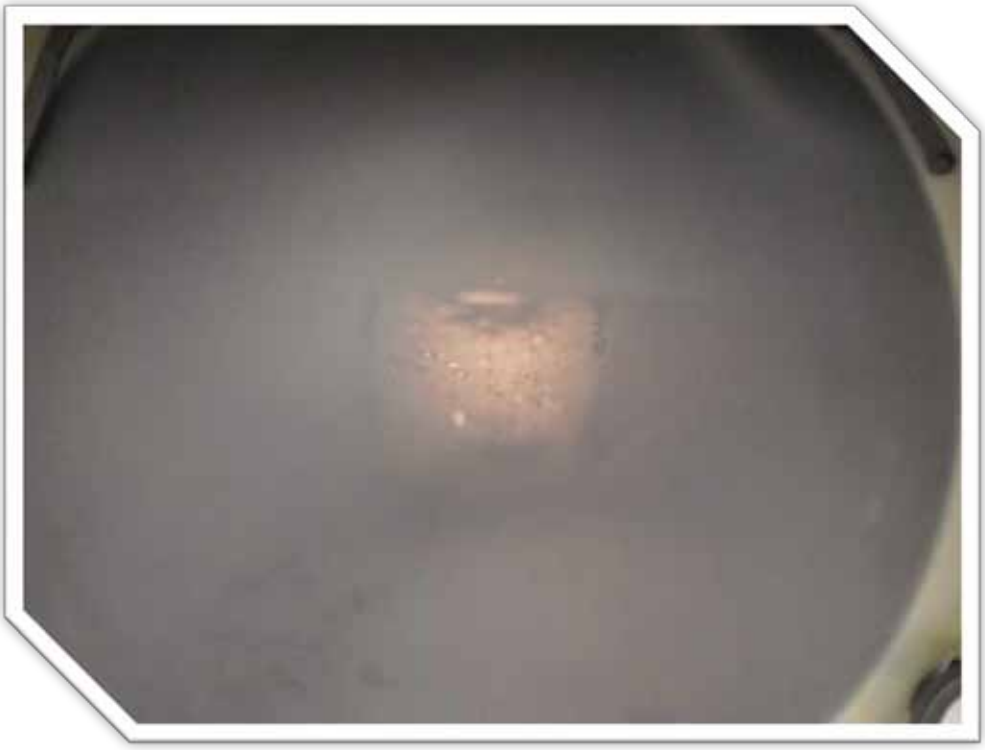
IN THIS SECTION:

- Ø Outer Gear Pictures
- Ø Reason for Damage

Outer gear showing damage:

Outer gear showing damage 2:

Outer gear showing damage 3:



Outer gear showing damage 4:

Outer gear showing damage 5:

Predicted cause for damage on out gear:

It is suspected that foreign debris harder than Rockwell C-16 entered the oil pump and damaged the sides. Pictures were taken using an optical comparator and a standard microscope, using a CCD device to obtain images from the Microscope.

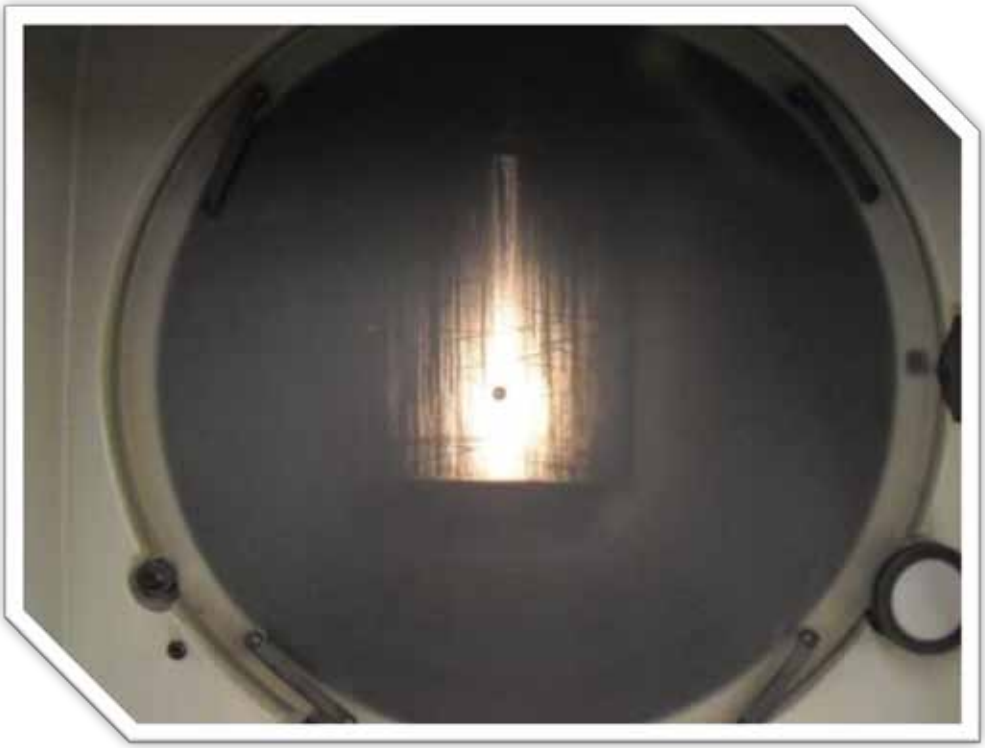
Relief Valve Failure Analysis

Relief Valve Details

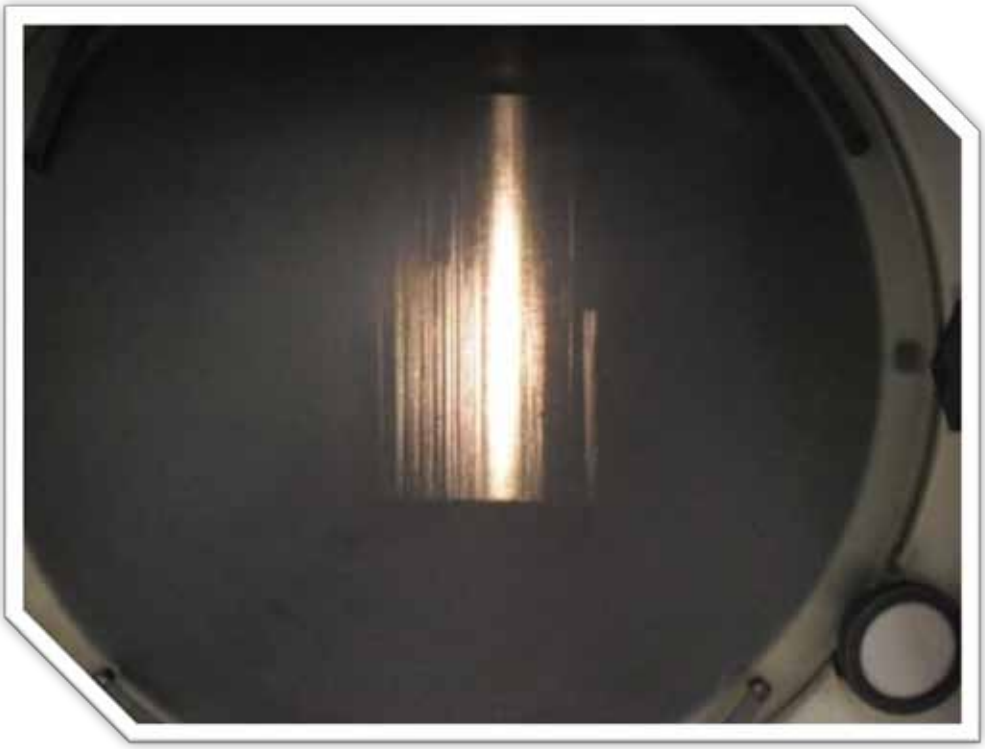
IN THIS SECTION:

- Ø Pictures of Relief Valve Damage
- Ø Pictures of Relief Valve Cylinder Damage
- Ø Reason for Piston Damage

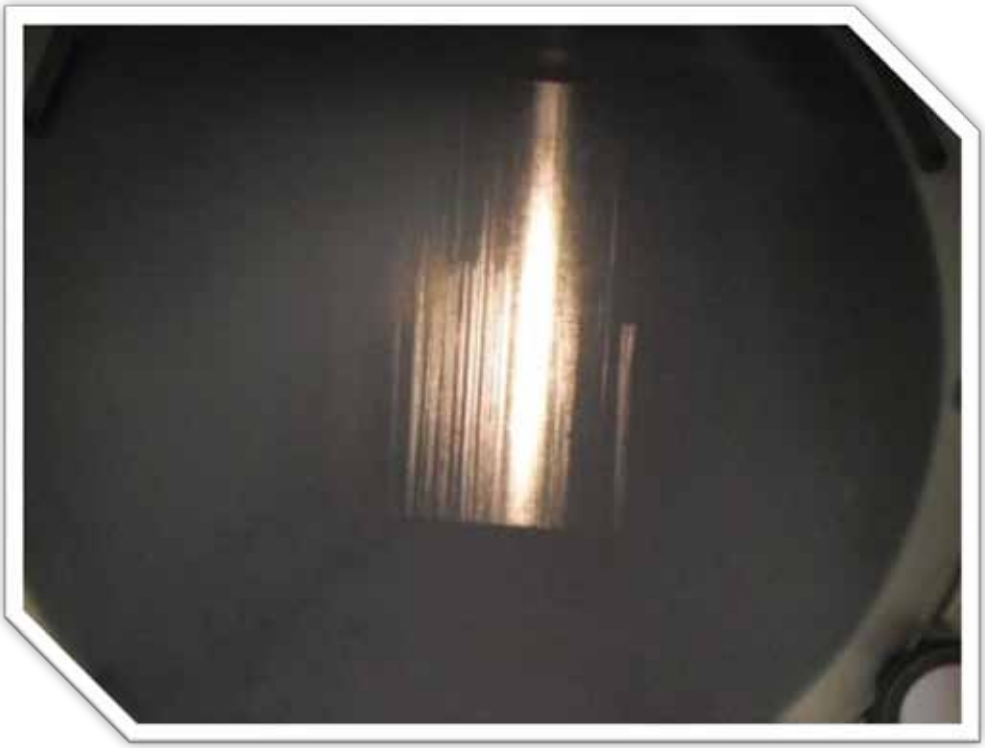
Piston showing damage:



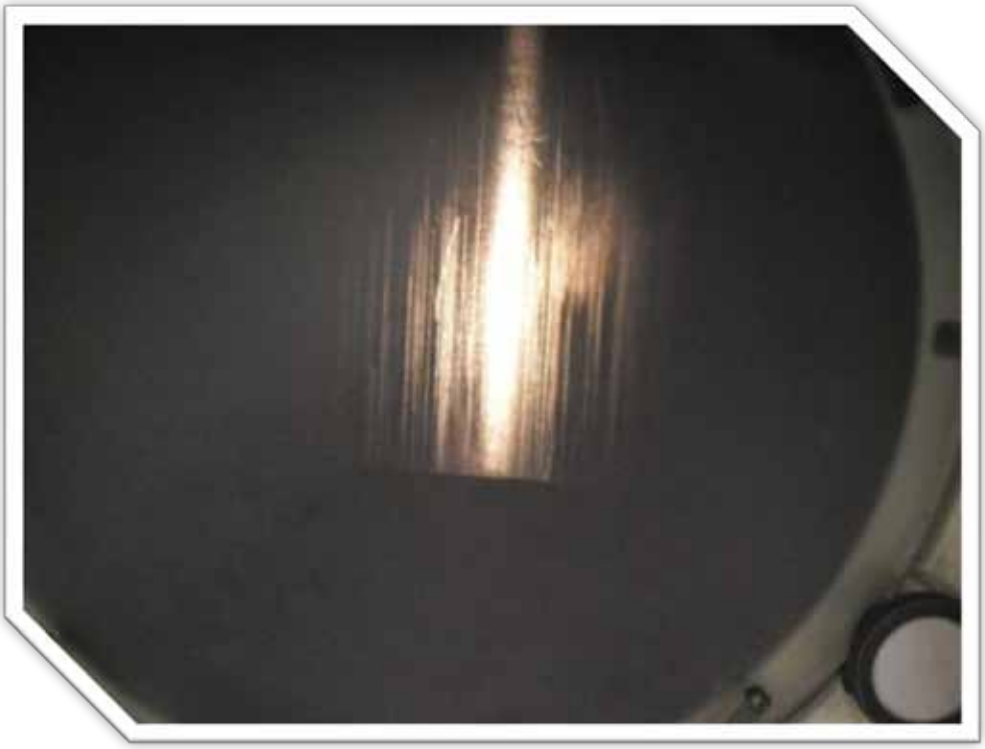
Piston showing damage 2:



Piston showing damage 3:



Piston showing damage 4:



Relief valve cylinder showing damage:

Relief valve cylinder showing damage 2:

Relief valve cylinder showing damage 3:

Predicted cause for damage on relief valve piston and cylinder bore:

The damage caused in the above pictures is believed to be from foreign particles harder than Rockwell C-25 hardness that entered the oil pump. Pictures were taken using an optical comparator and a standard microscope, using a CCD device to obtain images from the Microscope.

Relief Valve Failure Analysis

Conclusion of Analysis

IN THIS SECTION:

- Failure Analysis Statement from Stuart Dunham of Boundary Engineering Machining Division

Statement from Machining Division:

The photos of the gears, the housing, the cylinder, and the piston attached to this document each show unusual wear of the parts. Let me begin by listing my tests and observations.

Hardness

1) I did a harness test on the piston. The results were 25Rc. I tested both the end and the side and the results were the same. Using a file on the top, I tested it and it is as hard as a file.

2) I did a harness test on the gears and the outer was 14Rc and the inner was 16Rc.

3) I did a hardness test on the casting and the hardness was less than 1Rc.

Dimensions

1) Relief piston measures .6287-.6290 in.

2) Cylinder measures .6305 in. above and below the score marks

3) Outer gear measures .4086 in. wide, OD measures 3.1352 in.

4) Inner gear measures .4078 in. wide, bore measures 1.673, 1.481 in. across the flats

5) Tip clearance is .008 in.

6) Body clearance is .005 in.

7) Side clearance is .0015 in.

8) The depth of the gear bore in the housing measured with a depth mike reads .411-.4125 in.

Visual inspection with 10X microscope and 10X optical comparator

1) The gears show signs on their face of rubbing the aluminum housing. There doesn't appear to be any wear, just signs of rubbing. The outer gear has a few marks on it from the saw when the material was cut that did not clean up in the turning operation. The surface finish of the gears is 125 micro inches.

2) The gear teeth show multiple pock marks of varying depths and widths on their teeth. Some pocks are wider than .01 in., unfortunately the depth is something I cannot measure.

3) The piston has multiple scoring marks on the OD. Some are the whole length, others go about half way. There are even some scratch marks that circle the piston but I believe them to be from removing the piston after the damage.

4) The housing's cylinder walls have multiple scoring marks as well. There are bits of a foreign material embedded in the wall. This material is magnetic as I chipped a piece out and tested it with a magnet.

5) The bore of the housing where the large gear rides show a couple of small score marks.

6) The bore of the housing were the inner gear rides shows some wear on the top left as looking from the back.

7) The bottom of the bore where the gears ride shows some wear on the inner surface near the crank seal hole at the top left as looking from the back.

8) The spring and retainer appear normal.

9) The back cover showed wear and grooving up to .001 in. deep.

10) The pipe plug on the output side appears peened.

I do not believe the pump was started dry as I would expect to see the housing welded to the gears or signs there of. What I believe happened is a harder than 25Rc material entered the pump. I believe it was above 25Rc because of the scoring on the piston. It would also explain the depth and width of the pock marks on the gears. The harder the material, the deeper the penetration and a softer material would flatten as opposed to dig in. I believe the material was pumped to the relief piston and due to the clearance between the wall and piston, the pressure of the oil pushed the material down around the piston where it caused the piston to stick. When the engine warmed up, the cylinder expanded and the piston moved which caused the material to imbed into the walls of the cylinder where it would score the piston as it moved. When the engine cooled, the cylinder contracted and the material dug into the piston again causing it to stick when the engine was cold. This process continued for every cool down, warm up cycle.

I believe the material entered the pump and not originated in the pump for the following reason: The sides of the gears have no wear or scoring marks. Also the OD of the large gear has no wear or scoring marks. If the grease that was used for assembly had a foreign material in it, I would expect to see wear and scoring in those areas. The only places it shows up are on all the teeth of the gears and the relief valve.

In conclusion, I do not believe the pump was defective. The measurements are all in tolerance and there is no sign of negligence by any of the party's involved. I do not believe anyone to be at fault as there is no way to determine what the material is, where it is from and how it got there. I do believe it was an unfortunate happenstance.

If you or your customer have any questions, please feel free to call me.

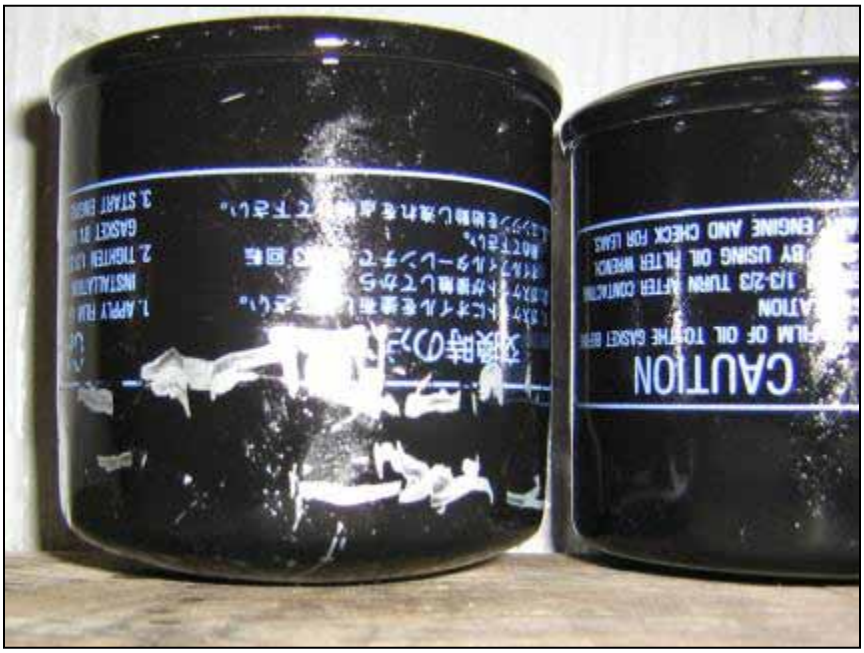
Sincerely,

Stuart Dunham

Appendix:

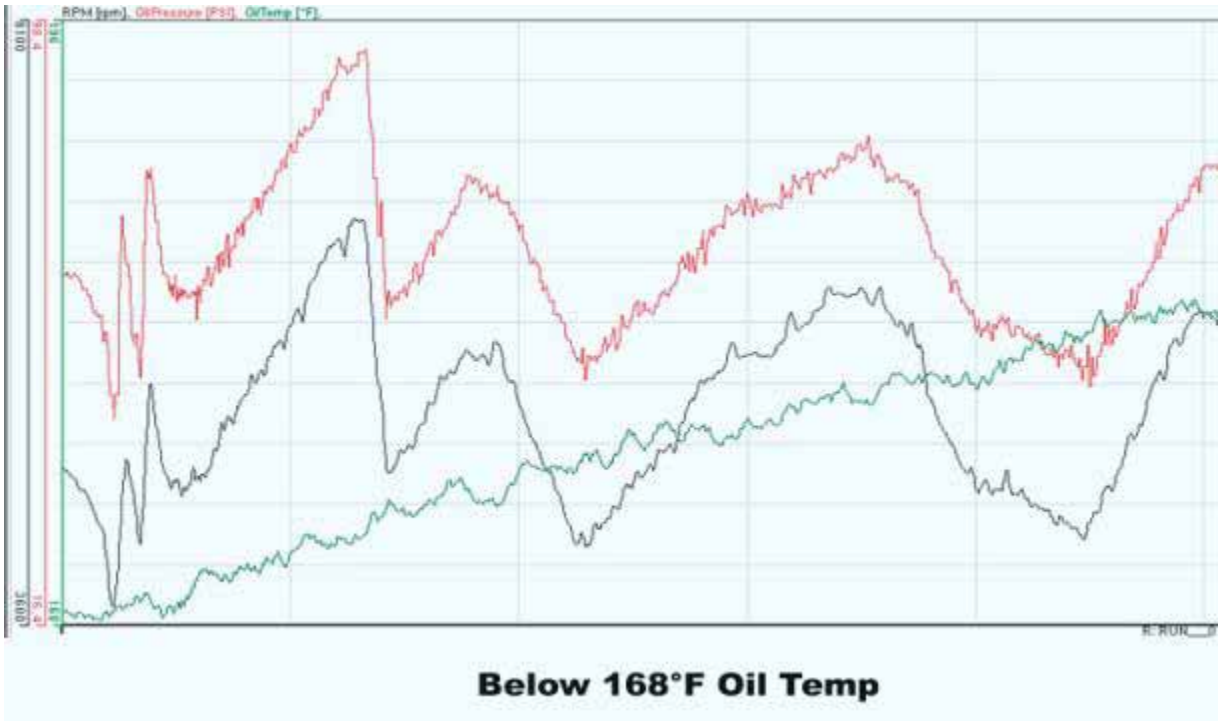
Item 1: Oil filter damage

Item 2: Oil filter damage 2

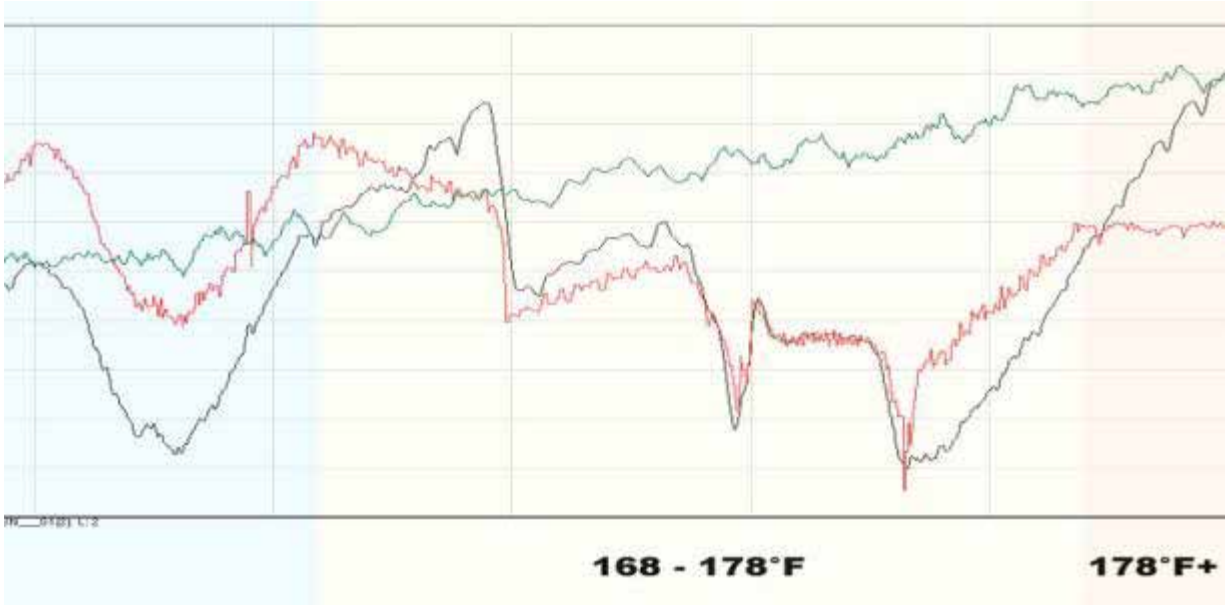


Item 3: Oil Filter Damage 3

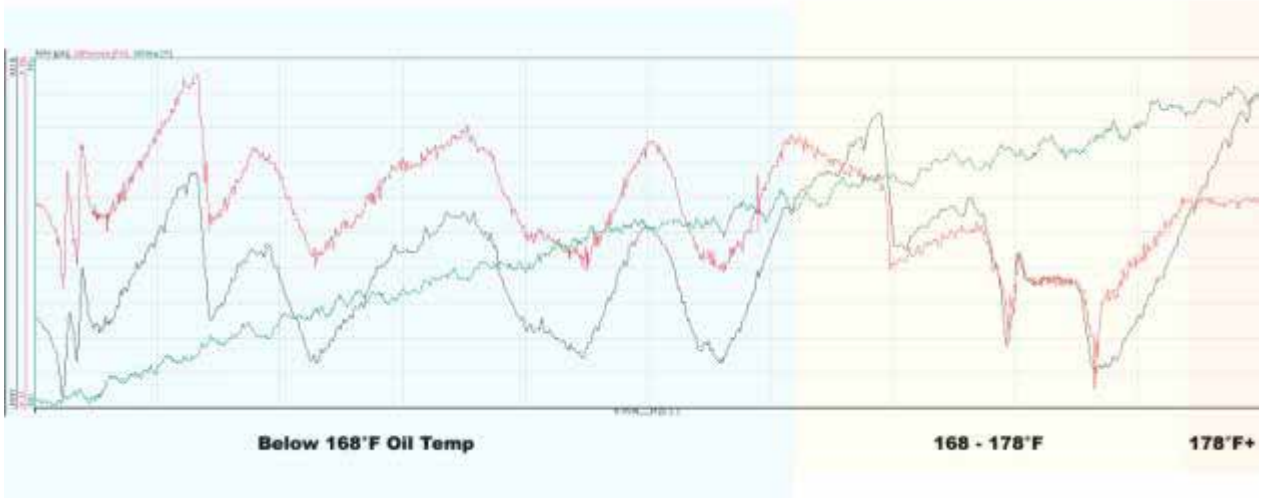
Item 4: Oil pressure with respect to RPM and temperature.



Item 5: Oil pressure with respect to RPM and temperature.



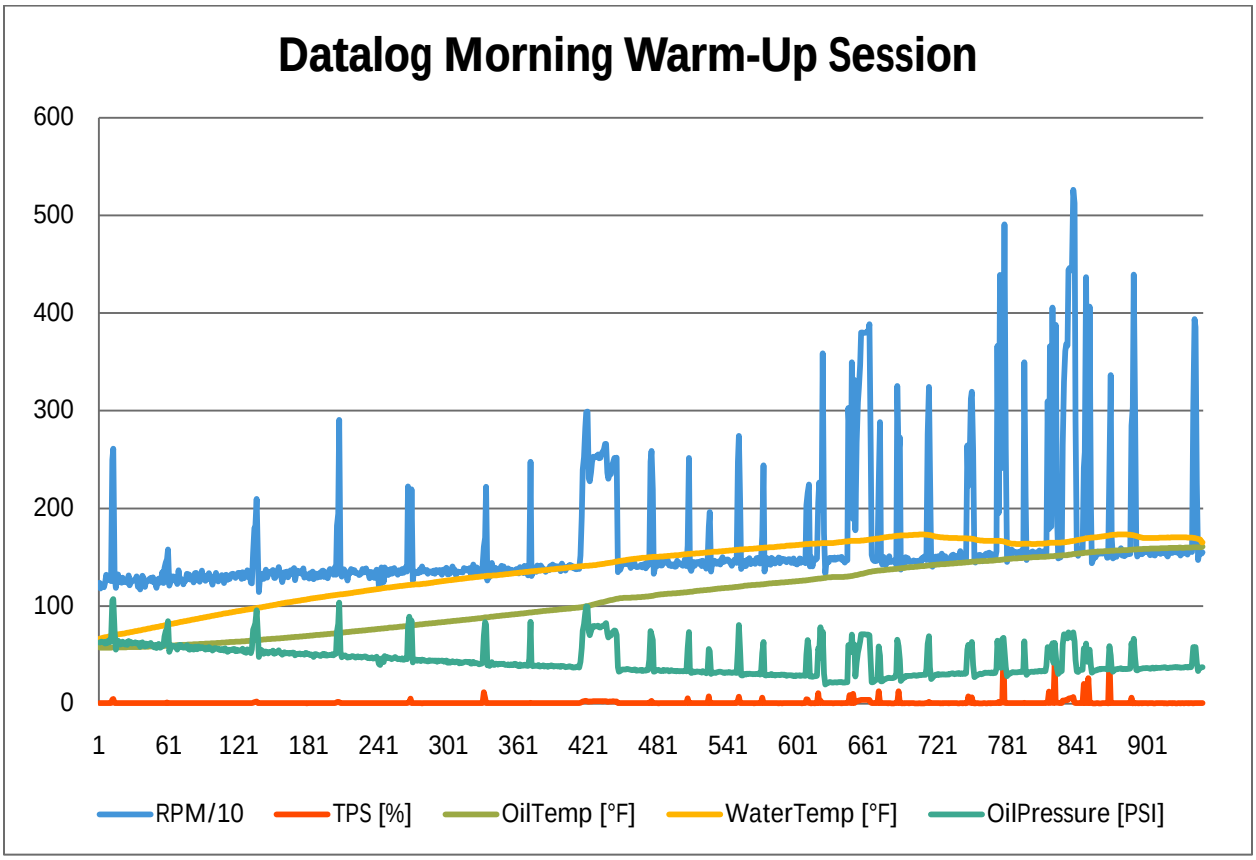
Item 6: Oil pressure with respect to RPM and temperature.



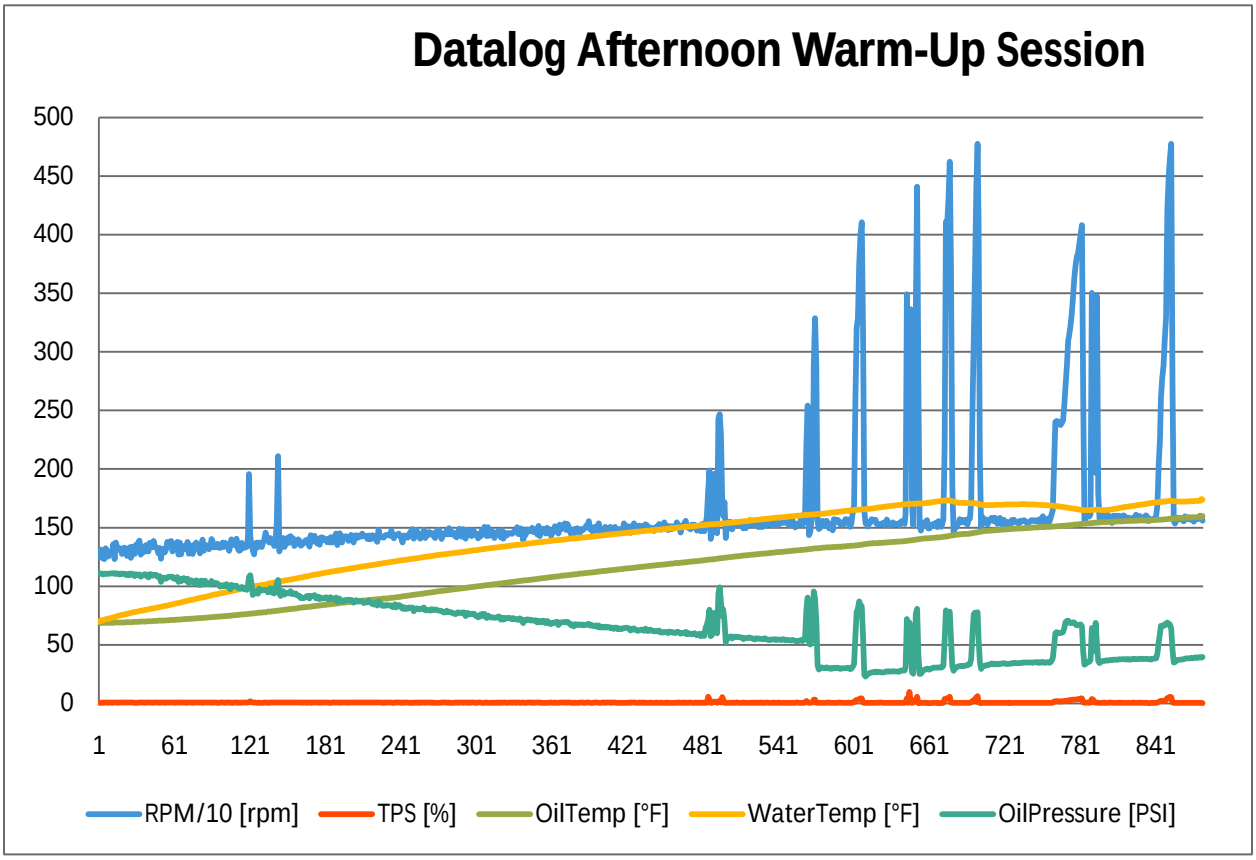
Item 7: Clearances of the bottom end of the motor:

	Factory Specification	Factory Max before rebuild	My Engine	Note
Main Crank Journals	0.0007 - 0.0014	0.004	0.002	Slightly above factory specs
Rod Journals	0.0011 - 0.0022	0.004	0.0025	Slightly above factory specs

Item 8: Morning cold start on 0w-20 Mobile 1.



Item 9: Afternoon cold start, no changes from figure 8's run, 0w-20 Mobile 1.



Item 10: Email excerpt outlining the customers ideas for why the pressure is high.

"At this point, and with 0w20 oil, I have to believe that there is something mechanical going on, no? The pressure relief valve stuck partially open? A sticky pressure relief valve that frees up when the engine comes up to temp? Oil passage blocked, then unblocked, then blocked? What is the spring on the pressure relief valve set to on the high-flow pump? Should the oil pressure ever get to 200 PSI for sustained time (not a spike)? Perhaps there is something wrong with this specific pump? The wrong spring used? A sticky relief valve piston? What have your other customers experienced with their pumps? Have they experienced anything like this?"

Item 11: Email from Boundary Engineering addressing the customers concerns.

"Hello Will,

I'm not sure what's going on here, but it is clear we have a mechanical blockage of some sort which is intermittent. I can see the "snap point" of the blockage on the second run. Your clearances are as you've said slightly on the loose side, but I don't even think the points I was making are relevant. I think we have some kind of mechanical problem as well.

I've sold hundreds of these pumps, and I've never had an issue at all, and definitely nothing even remotely close like the over pressure we're seeing here. We test all those parts for proper function, everything is properly packed with grease, and sent out the door. There is only one type of spring in the machine shop, and that's the one we use in this pump. Besides the pressure looks excellent when things seem to be working correctly.

The relief valve itself is set to open between 62-67. The valve can never control cold flow completely so that's normal for the pressure to exceed the relief valve setting, but the pressure should never go that high at cold. I would expect maybe a 100-110, but 200 is a sign something is wrong.

Now the way the system works, there are only a couple of conditions that can cause this. One is that the main outflow of oil is intermittently blocked to such an extent that the relief valve can't compensate. The intermittent block of the pump outflow is unlikely though without a whole lot of engine noise and torn up bearings. The oil filter is also after the relief valve so it should never see pressures like that.

Another is that the relief valve is just intermittently stuck. This could be caused by break in debris, or improper manufacture. We get the housings in brand new, and then test them for proper function. We don't actually manufacture anything in that area, we just fit the slightly stiffer spring, and move on.

I have seen a housing be damaged by debris from the break in procedure. He wasn't using our high-flow pump, but some of our billet oil pump gears in his own housing. When the engine was cycled something clogged the relief valve full open (suspected of being bead blast from the machine shop(NEVER SHOULD HAVE USED BEAD BLAST AT ALL!!!!), and the customer's engine was destroyed as a result. I wonder if something similar could have happened here(not bead blast but maybe just some break in particles)? I'm not out of the way of receiving blame on my end, it is just the only other oil pressure experience I've had with the complete Boundary oil product line that's been out of the ordinary. Really for the short duration this occurs you don't have any problems, but if the valve were to become stuck closed at full boil past 4000 you could be in for some interesting motor dynamics. I'm not sure what would happen, but 300+ PSI would probably be the end of the oil filter to say the very least.

The only thing I could recommend you try is to run something like seafoam through the oil system. This could loosen any organic compounds like RTV sealant enough to get whatever unstuck. If it's a metallic compound or just an improper fit from the manufacturer we get the housing from then there is little hope then to pull the motor and let us take a look at the pump.

Cheers,
Travis"

Item 12: Oil pump process sheet as sent to customer.

Oil Pump High Flow Assembly General Process Specification:

Casting receive process

1. Disassembly
    a. Remove back plate and remove gears
    b. Remove oil control valve lock ring, and remove spring, piston, and spring keeper (if
2. present)
    a. Remove front nose seal, high pressure seal, and any other wear items.
2. Check wear items to make sure all items are present that should be.
3. Hand de-bur all active areas of casting, and visual inspection for poor housing control.
4. Check taps, through holes, seals, and wear surfaces for grooves that cannot be removed
3. by machining.

Modification:

1. Machine housing internal to high flow specifications.
2. Measure housing post machining.
3. Use standard stock high flow gears and post OP Machine gears for measured housing dimensions.

Verification:

1. Verification of modification.
    a. Place gears in housing.
2. Rotate gears in housing for clean rotation check.
    a. Check tooth to tooth clearance to be within Mazda specification.
3. ii. Check body clearance to be within Mazda specification.
4. iii. Check side clearance to be within Mazda specification.

Cleaning:

1. All parts ultrasonic cleaned
2. All steel parts vibratory polished to remove burrs, and increase surface finish to specification

Assembly:

1. Assembly 1:
    a. Take relief valve piston move up into the bore
    b. Manually activate relief valve to full seated position from full open position.
2. Check for snags, improper activation, and burrs.
    a. Remove piston, reassemble with Teflon impregnated grease
    b. Insert spring, spring keeper, and spring lock.
3. Assembly 2:
    a. Fully encase outer gear in Teflon impregnated grease.
    b. Place outer gear into housing
    c. Fully encase inner gear in Teflon impregnated grease
    d. Place inner gear into housing
    e. Do oil pump gear spin check.
4. Assembly 3:
    a. Place back plate and torque to specification.
5. Do oil pump gear spin check.
    a. Place crank nose seal (if applicable)
    b. Place high pressure seal (if applicable)

c. Replace any other wear item to original location.

Shipping:

1. Seal pump in heavy mil air tight bag to prevent foreign contamination.
2. Pack pump tight to box to prevent shipping damage.

Item 13: Email from Boundary Engineering stating the reasons that the part is believed to have failed.

"Hello Will,

The analysis reads as follows:

We have evaluated all possible forms of failure and these were the principle failures we evaluated in the analysis

Improper housing torque causing the housing to be distorted and deformed.

Disassembly before part placement without proper pre-lubrication.

Debris getting into the pump from the engine break in process, or installation process.

Improper casting manufacturing.

Improper oil viscosity

Improper relief valve sizing to relief valve cylinder bore

Breach in quality control which caused parts to be assembled without regard to the specification sheet.

However, after the analysis and a second verification of measurements we have found the oil pump assembly from our process check was fine. As indicated by our records all clearances, and tolerances were met on the part that is evaluated and worked on. We are sure the problem occurred only after the car was run, and the pump was installed. As we had a verbal conversation about viscosity you were using oil in the range that is acceptable. The relief valve to cylinder fit was also verified to be the correct size.

That leaves us with the following failure possibilities:

Improper housing torque causing the housing to be distorted and deformed.

Disassembly before part placement without proper pre-lubrication.

Debris getting into the pump from the engine break in process or installation process.

Improper casting manufacturing.

We were unable to determine which of the items above were responsible for the failure. We do however know that the relief valve piston seems to be getting stuck on the relief valve cylinder as you determined at your shop regardless of the dimensions we are reading. Therefore it points toward either the casting being deformed, something being improperly manufactured/installed that caused an issue with the casting such as perpendicularity of the relief valve cylinder, or debris amalgamating to the relief valve and lodging the valve in the closed position.

Now given mutual trust and benefit of the doubt on the issue. We assume you are using a machine shop that is well qualified and we assume assembly was done properly. So that eliminates disassembly without pre lubrication and improper housing torque. We can only narrow it down to a problem that could be our fault, and could not be our fault. One would be a debris problem generated by sandblasting or engine wear. The other is a latent mechanical empathy problem with the pump casting caused by too much porosity in the casting material, or improper casting geometry that after being stressed and then heat relieved changed the casting shape.

Regardless of the uncertainty of whether or not the part we purchased, which is the housing, or a cleanliness issue is the problem we are going to furnish you with a completely new pump with a casting from another manufacturer at no charge with shipping. We have verified through a complete function check with pre-stress and heat relief that this oil pump assembly is 100% seasoned and to specification. Meaning that its geometries and function will not change once installed and ran. We have actuated the valve, we have turned the pump, and we have pumped oil into it to make sure the valve opens and closes correctly in situations that are equivalent to running the part on the engine. As I had indicated on the phone your pump did receive the black oxide rear finished plate upgrade free of charge as well for the hassle.

Some things to check when you reinstall:

Be sure the front of the block is flat for the mounting. A significant slant or wave could cause problems.

Be mindful of torque specifications as extreme or lax torques could cause deformation of the housing.

Be mindful of poor pin holes in the block that have broken or deformed edges that could stress the oil pump housing to an extreme.

Be mindful of the oil pan mating to the pump that it easily lines up without force or manipulation.

If it was our fault, which I don't think we will ever really know, I once again very sincerely apologize for the inconvenience this has caused you. I know it has to be horrible to finally get a build like that together and then run into this much trouble. I take customer satisfaction very seriously, and we were very thoughtful and in-depth in looking for failure modes with your part because it is important to us that our parts perform at a very high level.

Your package will be shipped tomorrow and should be received by Thursday or Friday this week.

Let me know if you have any other questions about this process.

With Regards,
Travis Rosenbarger
Boundary Engineering
1087 Baylor Wissman Road
Georgetown IN 47122
(812) 989-3308"