Figure 14: Turbine Housing "C" - 0.92a/r Wastegated

EFR turbine housing “D” is also a divided (twin-scroll) housing but is not wastegated. Targeted at those who are comfortable using two external wastegates or are already set up in such a configuration, this part will likely be the most popular on dedicated drag race machines. It is constructed with a larger volute than the “C” housing, this one being 1.05 a/r. It is also adjusted so that it can accommodate the largest of EFR wheel sizes, the 80mm. It is also offered for the 64mm, 70mm, and 74mm wheels. The housing has a very short axial length and is designed to be a “drop-in” for customers already running a T4-inlet divided housing with external wastegates.

Figure 15: Turbine Housing "D" - 1.05a/r Non-Wastegated

<u>Summary</u>

Turbine and compressor aerodynamics are truly “top shelf” in the EFR product line. Choices have been made that embody the current state of the art and include the latest and greatest techniques also being offered to our OE customers today. Combined with the other features like ball bearings, the compressor cover refinement, and Gamma-Ti turbine wheels (to be further discussed in other chapters), it has been our intention to maximize the performance of these turbos in every possible way.

Chapter 4: EFR Wastegate System

As mentioned in the introduction, internally-wastegated housings of the past have usually been castings that were handed down from prior diesel applications. As part of offering a diverse “performance” product line, it’s logical to make use of any casting that is available and might be of use to someone. However, these housings have had limitations. They have almost always had small wastegate ports that were quite suitable for diesel use but often not sufficient for “gasoline” levels of wastegating. Material specification has also been an issue, with most of these housing made from ductile cast iron of one flavor or another but rarely of a material truly suited for high-temperature operation. This is particularly noteworthy for wastegated housings, since the wastegate seat can be the “fuse” for thermal fatigue failure.

As part of our “clean sheet” approach, we wanted to make internal wastegates that were capable of handling the flow requirements of high performance applications. We use matching calculations that predict the level of wastegate flow required for any given match. By using a conservative flow coefficient assumption, we can predict how much flow will pass through a wastegate port of a specified diameter, motivated by the expansion (pressure) ratio across the turbine stage. Using this method, the wastegate can be sized on a match-by-match basis. This procedure was followed for a wide range of matches (displacements, power levels, engine speed ranges, turbo sizing) at the beginning of the project. It was decided that a 31mm port (36mm valve head) would be sufficient for the smaller turbine housing, and a 36mm port (42mm valve head) would be used for the larger housings. 36mm may not sound that much larger than 31mm but in fact it’s 35% more flow area.

Figure 16: Large Internal Wastegate

There are downsides with going too large, so we knew that we were walking a fine line. A wastegate that is too large can be fickle to control since a very small valve opening can then result in a very large increase of flow. In other words, if only 50% of the rod stroke is used for max wastegating flow need, then the control resolution is half of what it could have been. Also, packaging dimensions (housing physical size) suffers as the wastegate valve head grows in size.

Figure 17: Wastegate Valves - 36mm and 42mm

The wastegate valve, shaft, bushing, and lever materials are investment castings of premium materials. The valve heads have anti-rotation tabs to prevent vibration-induced skidding wear. Lever arm kinematics were selected to be a match with available rod stroke, yielding approximately

50 degrees of valve motion – sufficient to achieve maximum port flow. Another nice mechanical element is the lever's swivel-block due to the easy adjustment. The wastegate canister has an output rod and the end of this rod is threaded. The thread is M6 x 1.0 which means that each full turn of the nut equals a 1mm change in extension. By tightening the nut one turn at a time, a known preload (1mm) can be applied to the rod and canister spring. As preload is added, the spring inside the canister compresses and exerts more force to hold the wastegate flap closed. The downside of added preload is loss of stroke. In other words, the rod travel that is consumed by preload setting is no longer available for rod stroke motion (during use). The valve will not be able to open as far, so maximum wastegate valve flow will be limited.

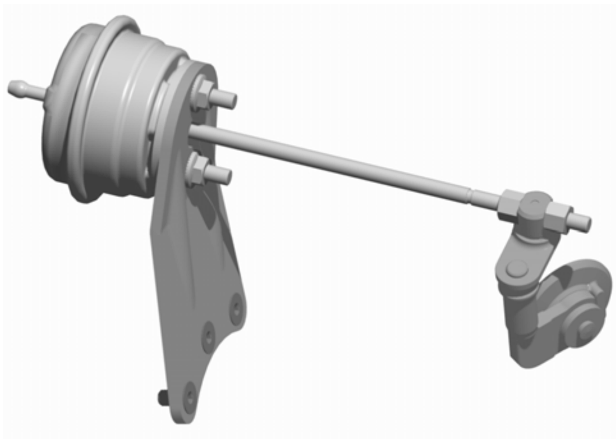
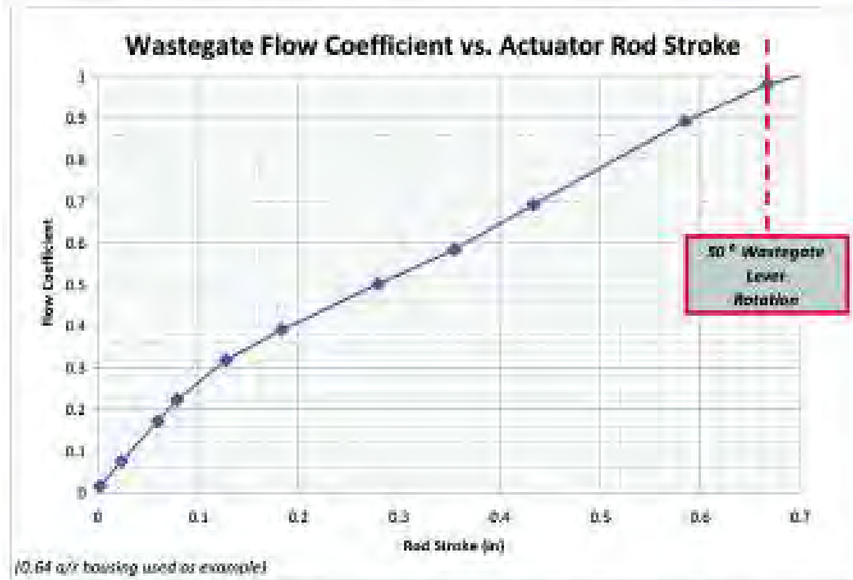


Figure 18: EFR Wastegate System



The flow coefficient is a measure of to what extent the wastegate port area is being used. When a pressure drop is applied to any orifice, orifice flow equations can be used to calculate what the theoretical maximum flow is through the hole. If the flow coefficient reaches 1.0, then that means that the port is being fed efficiently and that the port area is being used to the maximum extent. In this example, once the lever angle reaches about 50 degrees, the valve is sufficiently out of the way and the port is flowing at the max capability. From studying this plot, you can see why achieving a large stroke from the canister is important if the wastegate is being used for a large fraction of the total exhaust flow. This is particularly important with low-boost applications since higher wastegate flow fractions are required. More highly-boosted applications require less WG flow fraction since more work extraction (read: more turbine wheel energy) is required to power the compressor.

Figure 19: Wastegate Flow versus Opening Angle (Rod Stroke)

Turbine housing porting was also done with care, giving as much attention to the gate channel(s) as given to the rest of the volute entry throat. This is a compromise with outer elements such as overall housing height and stud/nut wrench access, but given these constraints the ports were smoothed, blended, and sized generously. Of particular challenge is integrating a smooth pair of wastegate channels into a twin-scroll housing. The “C” housing is of this type and requires bit of twist on the volute throats in order to wrap both wastegate channels towards the outlet, heading towards a Siamese (double-D) valve seat.

This is a superb housing for users of “divided” systems (with twin-scroll housing) since it avoids the need to buy, mount, and plumb two external wastegates.

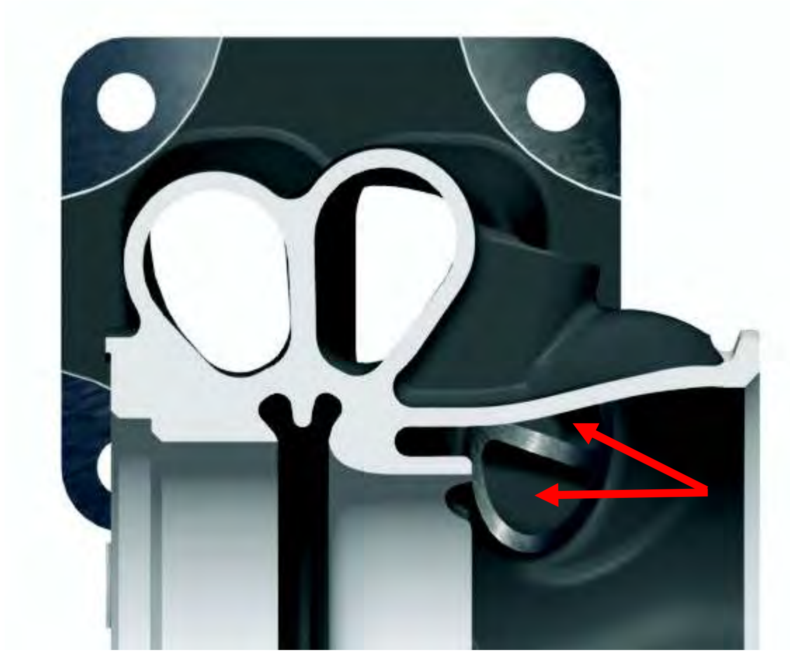


Figure 20: Turbine Housing "C" (0.92a/r) with Dual WG Passages

Wastegate behavior is tuned in two ways. First, the wastegate canister is selected. Second, the rod preload is set. There are three canisters offered, simply called “low boost”, “medium boost”, and “high boost”. As you would expect, the “low boost” actuator requires a low pressure to be applied before cracking the wastegate open. It is also sprung quite softly, so as canister applied pressure increases, the amount of rod movement increases quickly. This actuator is meant for vehicles running low boost pressures (less than 10psi) or vehicles running medium boost (10-15psi) that have an electronically-controlled spill valve (e.g BCSV) on the actuator line. The “medium” boost actuator is the default on EFR turbos and is targeted at the user running 12-18psi boost pressure straight off the supply hose or with mild amounts of electronic spill control. The “high” boost actuator is quite stiffly sprung and is reserved for those running 20-30psi boost (or higher, when using spill). The rod preload is the fine-tune adjustment, and as mentioned above it's easy to count turns and know how much preload (rod extension) is being added. Graphs are supplied that gives wastegate canister stroke response as a function of preload and applied pressure.

Rod & Spring Preload	Full Stroke Capability	179282, 179420, or 179285 Low Boost WG Canister		179283, 179421, or 179286 Medium Boost WG Canister		179284, 179422, or 179287 High Boost WG Canister	
		Crack Open Pressure (psi)	Full Stroke Pressure (psi)	Crack Open Pressure (psi)	Full Stroke Pressure (psi)	Crack Open Pressure (psi)	Full Stroke Pressure (psi)
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	0.59" (15mm)	5.7	14.0	10.8	20.6	17.6	32.3
3	0.55" (14mm)	6.1	14.1	11.2	20.6	17.8	32.3
4	0.51" (13mm)	6.8	14.3	11.9	20.6	17.9	32.3
5	0.47" (12mm)	7.3	14.6	12.1	20.6	18.1	32.3
6	0.43" (11mm)	8.0	14.4	13.2	20.6	18.6	32.3
7	0.39" (10mm)	8.5	14.8	14.0	20.6	19.0	32.3
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Figure 21: Actuator Preload and Available Stroke Chart

The best control is achieved by using an electronic spill valve. This valve "vents" pressure from the wastegate canister's signal port. The net effect is that the canister can have a non-linear response to applied pressure and a more precise opening point and opening rate. When using a spill valve such as the one supplied with EFR turbos, the canister selected should be relatively softly-sprung. Why? With a valve, you can always lower the pressure making its way to the actuator, but you can't raise it. Also, the valve can vent all the signal pressure until it's time to open the wastegate. If you want a real punch in the mid-range, this is how to achieve it. The limiting factor for selecting a "softly sprung" canister (low boost) is the risk of premature wastegate valve opening. While not damaging in any way, it will soften up the boost response and can actually be a useful attribute on cars that are having traction problems when boost hits. Premature wastegate opening can be overcome by adding preload in most cases, but if extreme, the wastegate valve will blow open when exposed to turbine inlet pressures prior to when it is commanded to open by the actuator. The EFR actuators are sold separately, so if an alternate choice is needed, it's an inexpensive and easy swap.

EFR Wastegate Canister Selection Guide			
Core Assy	0.64a/r TH	0.83a/r TH	0.92a/r TH
6255	179282, 179283, or 179284	N/A	N/A
6258	179282, 179283, or 179284	N/A	179420, 179421, or 179422
6758	179282, 179283, or 179284	N/A	179420, 179421, or 179422
7064	N/A	179285, 179286, or 179287	179285, 179286, or 179287
7670	N/A	179285, 179286, or 179287	179285, 179286, or 179287
8374	N/A	179285, 179286, or 179287	179285, 179286, or 179287
9180	N/A	179285, 179286, or 179287	179285, 179286, or 179287

Figure 22: WG Actuator Canister Matrix

The most common problems occur at each end of the extreme:

Lazy boost onset or wastegate blowing open

- Canister spring too soft (use "medium" or "high")
- Not enough rod preload (tighten nut to add preload)
- No electronic intervention (spill valve can block pressure signal getting to WG can, hence delaying the opening)

Boost creep (overboost at high engine rpm's)

- Canister spring too stiff (use "low" or "medium")
- Too much rod preload (loosen nut to allow more rod stroke)
- Actuator/preload/spill combination not allowing full rod stroke at full boost condition
- Solution: Make sure actuator rod is achieving full stroke at max boost and high RPM (video-record, if required)

In extreme cases, the EFR wastegate port will not be large enough. It is sized to provide capacity for up to 40% of the engine mass flow to bypass the turbine wheel. However, on applications using very low boost pressures on large engines, little turbine power is required to satisfy the boosting task and as a result the need for wastegate flow is extremely high. In this type of scenario, there may be no other solution than a very large external wastegate. There are many on the market and the keys are to plumb the flow well and to buy a quality product. Keep in mind that these devices have an elastomer of some kind (either an o-ring or a diaphragm) that is in close proximity to exhaust gas heat. It's for this reason that we shy away from external wastegates, but if you do need one, buy the best you can afford.

The last topic is wastegate canister mounting. The canister bracket connects to the front face of the bearing housing, on the compressor end. This is a relatively cool location and keeps heat conduction (to the actuator) to a minimum. Furthermore, both the bracket and the output rod are stainless steel which further reduces the conducted heat. The bolt pattern on the bearing housing face is drilled in 15° increments which maximize the canister mounting options. Since the actuator mounts to the bearing housing, the bracket location will have to be adjusted simultaneously when the turbine housing to bearing housing orientation is adjusted.

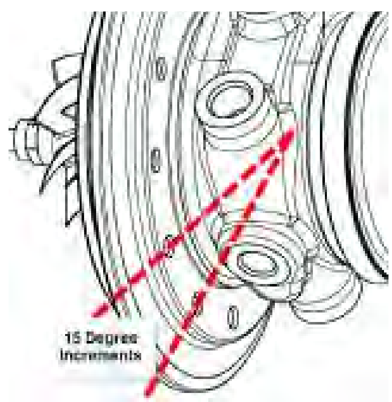

Figure 23: Actuator Bracket Able To Be Rotated in 15° Increments

Chapter 5: EFR Bearing Systems

The barrier for widespread use of turbocharger ball bearings continues to be cost. While the pricing is coming down amongst the global supply base, this is the primary reason as to why journal bearings continue to dominate worldwide OE turbo production. Current state of the art in rolling-element turbo bearings is to use ceramic balls and specialized race materials. EFR turbos use these premium materials and are designed and tested with commercial-duty longevity in mind.

Figure 24: Ball Bearing Cartridge

Figure 25: Bearing Disassembled; M50 Races, Metal Cages, Ceramic Balls

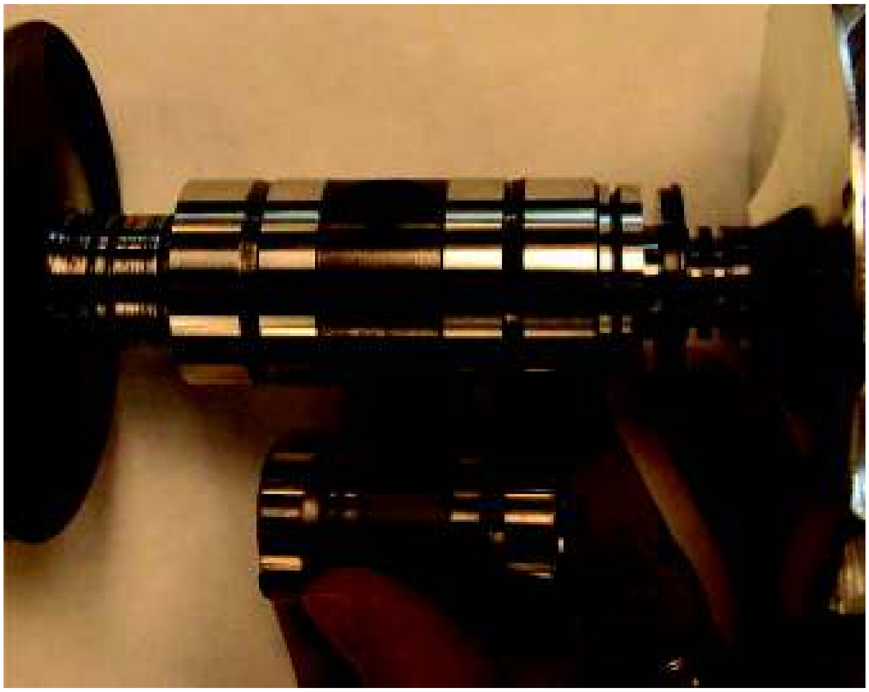

Figure 26: Which Would You Rather Have Supporting Your 500hp Application? (BorgWarner B2 vs. Competitor)

Figure 27: Competitor's Plastic Cage and Steel Balls

Ball bearing systems reduce friction losses as compared to their journal bearing counterparts. These friction losses are measureable on a combustion gas stand and are quantified by a gain in calculated turbine efficiency. Because it is difficult to separate the effects of mechanical efficiency (from the bearing system) and turbine efficiency, the SAE convention is to report the two as a “combined” efficiency. The combined efficiency is simply the multiplication of the thermodynamic turbine efficiency times the mechanical (bearing system) efficiency.

The friction loss is considerable at low turbo speeds and low shaft power. At these conditions, the power required to overcome friction is a larger fraction of the total power such that when reduced with ball bearings it accounts for a large improvement in combined efficiency. At higher speed and shaft power, the savings are a much smaller percent of total such that they become negligible. For this reason, the efficiency enhancement from a ball bearing system benefits the spool-up period and the light-load (low boost) regions of operation. The effect is most noticeable on a street machine coming in and out of boost and not as much at the drag strip. Using a drag race vehicle as an example, once it leaves the line it’s always up on boost. Once on boost, the advantages of ball bearings erode so most drag race applications won’t see much performance advantage from ball bearings. It’s for this reason that our large S400SX and S500SX drag race turbos will likely retain conventional bearings for the foreseeable future.

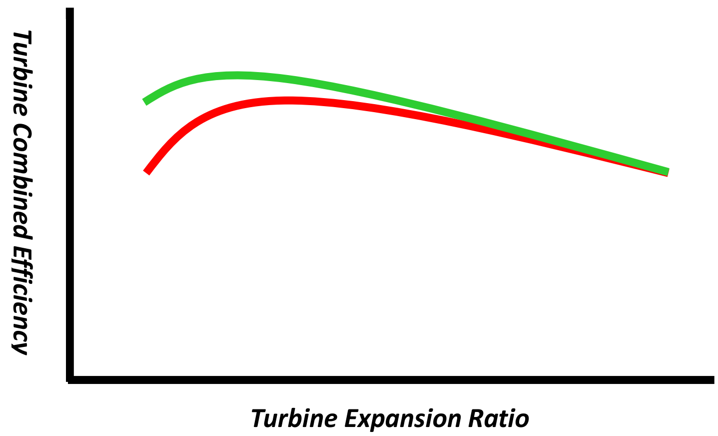

Figure 28: Low-End Efficiency Gain (Green) From Ball Bearings over Conventional System (Red)

The ball bearing system can survive substantially higher thrust loads than a hydrodynamic thrust bearing. The ball bearing is much better at surviving abuse such as compressor surge, marginal oil quality, low oil pressure, and harsh acceleration. The thrust capacity of a ball bearing is believed to be about 10X that of a conventional thrust bearing but to be honest we don't know the exact figure because our thrust load test rig cannot currently develop enough force to overload one. We do know that it has at least 5X the capacity. Unlike the conventional system where higher axial load capacity comes at the expense of friction losses, the thrust capacity of a ball bearing is "free", by comparison, when it's not heavily loaded.

Oil flow requirement is another key distinction. The ball bearing system does not require much oil to function properly. We have integrated an oil restrictor into the bearing housing so an external orifice SHOULD NOT BE ADDED. The oil does provide a cooling function in addition to keeping the ball raceways lubricated, so the oil flow will continue to be 25-50% of that required for a conventional system. A -4AN male fitting has been provided on the EFR turbo and a -4AN (1/4") line is sufficient as long as the engine supply pressure is healthy and the line(s) are kept short. If the line is longer than about 18" then it's advised to step up to a -6 supply line. This is most critical for people living in cold climates.

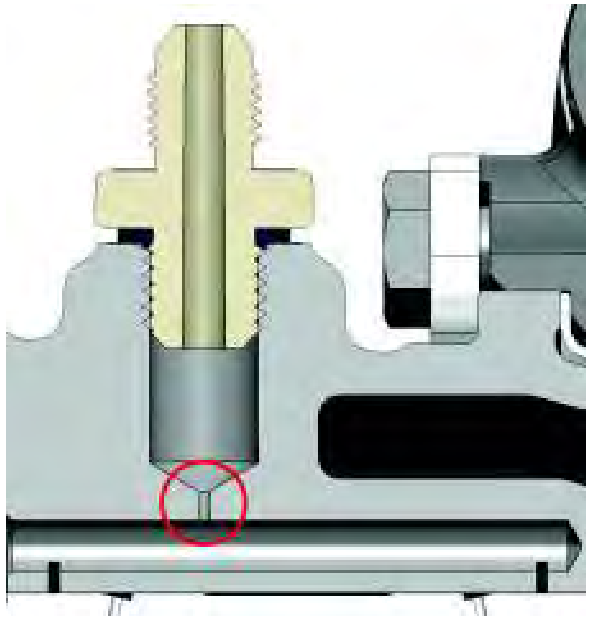

Figure 29: Oil Restrictor Integrated Into Bearing Housing

Figure 30: -4AN Oil Inlet Fitting (Supplied)

The EFR turbo also uses our top-shelf sealing system which includes two compressor piston rings placed in separate grooves as well as two turbine rings also placed in separate grooves. These features along with other geometric techniques provide a very effective oil sealing function as well as good blow-by resistance. Blow-by (the boost and exhaust pressure gases entering the bearing housing) has been reduced by 50% over the levels seen in prior generations of turbos. This sealing system along with the extended bearing span (for added stability) do make the center section quite long, and is the only drawback of the EFR internal component selections. This is a clear example of priorities: function and durability comes first.

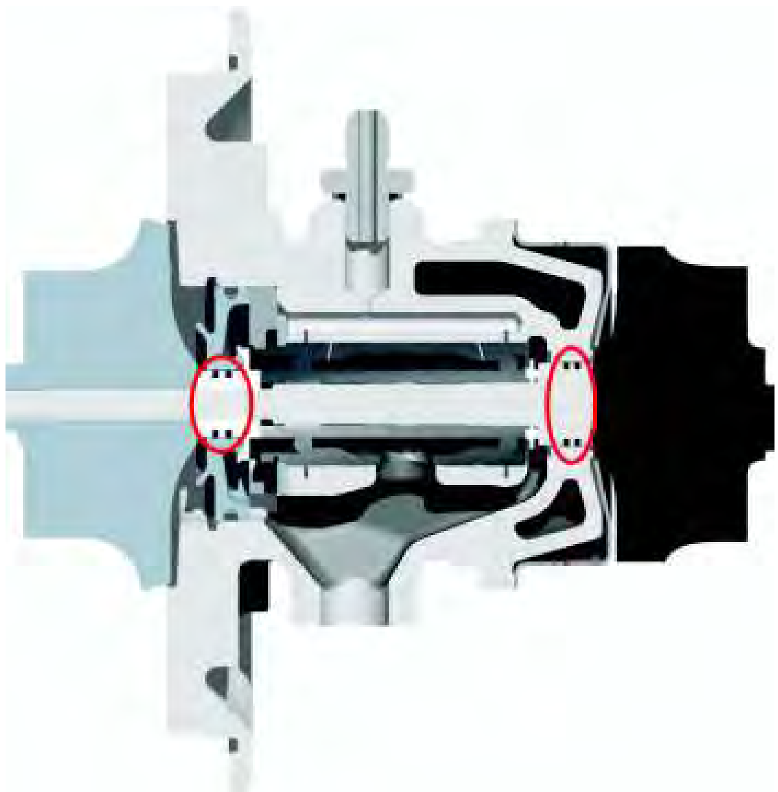

Figure 31: Dual Compressor and Turbine Piston Ring Seals

The bearing housing oil drain is machined for two connection types. The oil drain port is tapped with 3⁄8-NPT threads for those who want to install a fitting. A fitting with 3⁄8-NPT on one end and -8AN on the other makes for a very nice solution. The through-bore of such a fitting is about 0.42", which then spills into a 0.5" ID drain line. For those wanting to install a gasketed flange, two M8 holes are provided with a centerline span of 1.5".

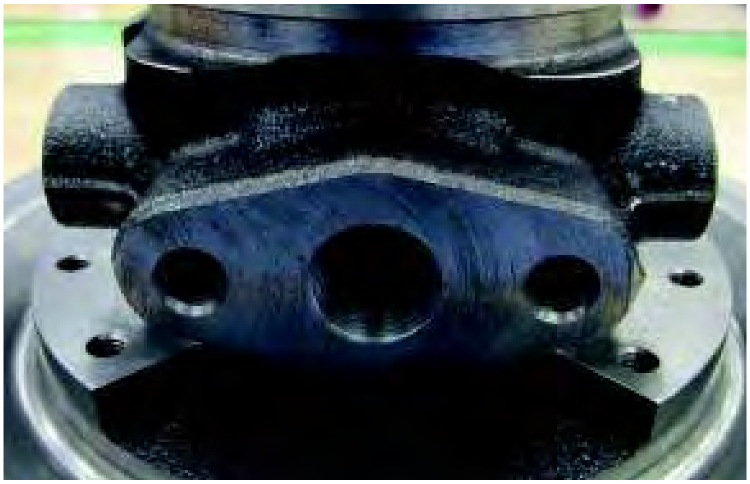

Figure 32: Oil Drain Pad Machined for Gasket and 3⁄8 NPT Fitting

Figure 33: Oil Drain Fitting Installed (-8AN)

The bearing housing castings are water-cooled, and four M14x1.5 ports are provided. Two plugs are also provided so that the ports not being used can be capped off. It does not matter which side of the bearing housing gets the inlet flow and which side gets the outlet flow, but the flow must be diagonal across the housing. Also, the inlet port needs to be on the bottom and the outlet port needs to be on the top. This is to encourage evacuation of air bubbles as well as to encourage auto-siphoning (flow movement through natural convection) during the shut down's heat soak.

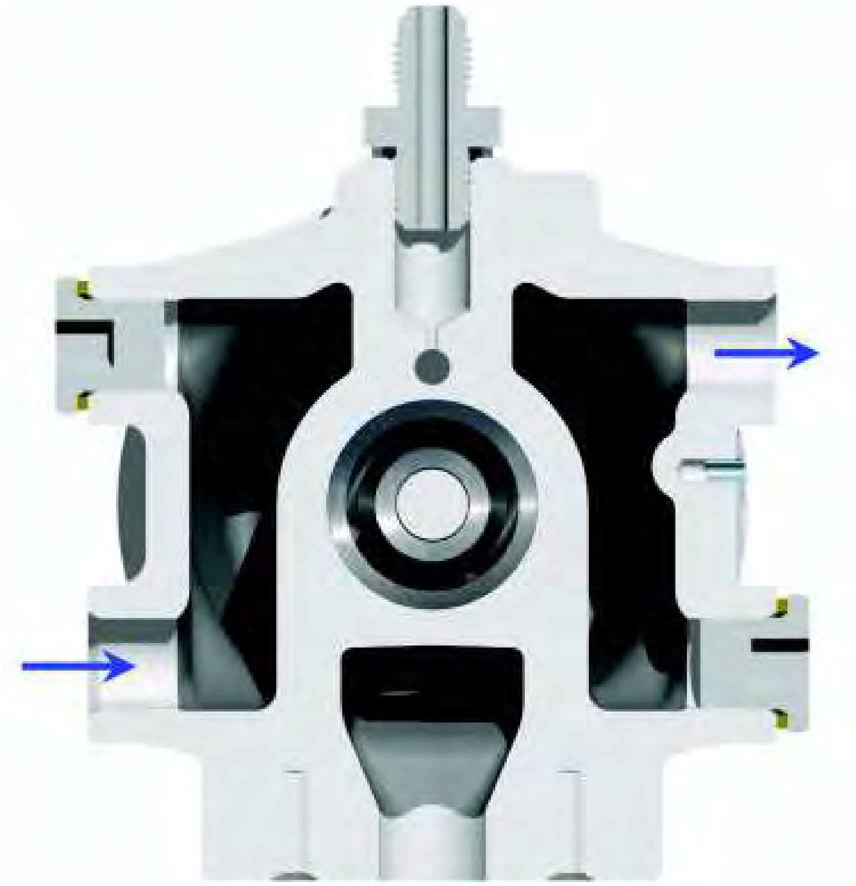

Figure 34: Cross-Flow (Bottom to Top and Side to Side) Nature of BH Water Cooling Plumbing

Figure 35:   Series EFR Bearing Housings, B1 (back) and B2 (front)