Whitepaper

CorkSport Max Flow Fuel Pump Internals

for Mazdaspeed MZR Turbo

"The difference is safer air/fuel ratios and the ability to go to high power levels without worrying about your fuel supply."

Table of Contents

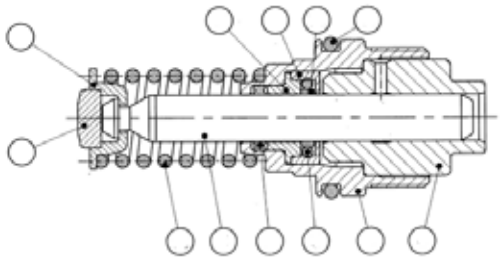
Introduction

After almost three years of testing, design and research, CorkSport is proud to announce its release of the High Pressure Fuel Pump Internals kit. This kit is engineered to reliably provide an increased volume of fuel while retaining the extremely high pressures required by the Mazdaspeed direct injected MZR engine.

The kit utilizes a completely new design by integrating a unique combination of materials, coatings, geometry, and manufacturing processes. Our pump internals outperform others on the market, come with all the needed parts and include the tools and instructions to do the job right the first time.

Hitachi Mechanical Fuel Pump – The Basics

We started our pump design process by researching the cost and function of the factory Hitachi pump.



CorkSport Drawing of Hitachi Internals

The factory pump uses a combination of mechanical and electronic components to create almost 1800psi of peak fuel pressure. For comparison, most traditional fuel injected cars have around 45psi of fuel pressure.

The pumping action comes via lobes on the engine camshaft. This motion is similar to how a valve is opened/closed by the camshaft. The pump speed is therefore engine RPM dependent. A solenoid is used to control pressure to a set point. Were it not for the pressure control system fuel pressure would rise to unsafe levels very quickly.

It is well known that the factory pump is designed to specifications that deliver just enough fuel to operate the MZR system in stock form.

The benefits of the Hitachi design are; a relatively simple piston and sleeve design that limits side loading of the piston. Because of this, the manufacturing process of the stock pump piston requires only a simple and less expensive hardening of the piston material and cylinder.

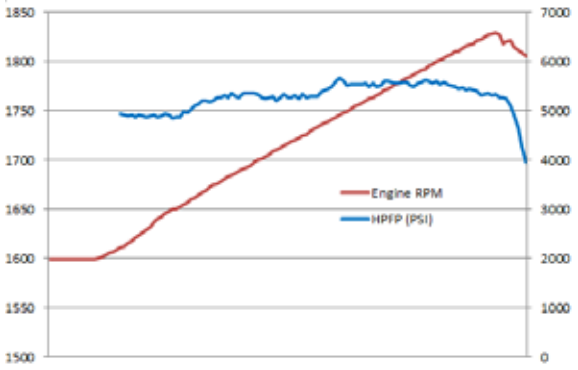
Appendix 1 shows an exploded view of the Hitachi pump. This pump has many features to help reliability.

- *Fuel Return/In-tank Pump Feed*
  The input from the fuel tank and the return from the fuel rail. The fuel rail is mechanically regulated to about 1750psi.
- *Mechanical Damper*
  The fuel then enters a chamber with a wave spring and discs to reduce the changes in fuel flow.
- *Spill Valve*
  The spill valve opens and closes a mechanical check valve in order to let fuel into the mechanical fuel pump chamber. This also allows the electronic adjustment of how much pressure is sent out to the fuel rail.
- *Mechanical Fuel Pump Chamber*
  The heart of the pump. In this chamber the volume of fuel is pressurized. The larger the fuel pump internals the larger the potential volume of fuel.
- *Final mechanical Check Valve*
  This is a ball and spring that stops the pressurized fuel in the fuel rail from coming back into the mechanical fuel pump chamber.

When it's Necessary to Upgrade Internals

During development of the CorkSport Max Flow Internals the limits of the stock fuel pump were determined. It was obvious very early on that the pump was only designed to support the stock power level of the Mazdaspeed3.

The chart below shows a stock car in 4th gear runs on an in-house Dyno Dynamics dynamometer. 1750 psi is targeted and delivered by the factory pump at stock boost. Boost runs around 13.5psi from the factory.



Stock Car at 13.5 PSI of Boost

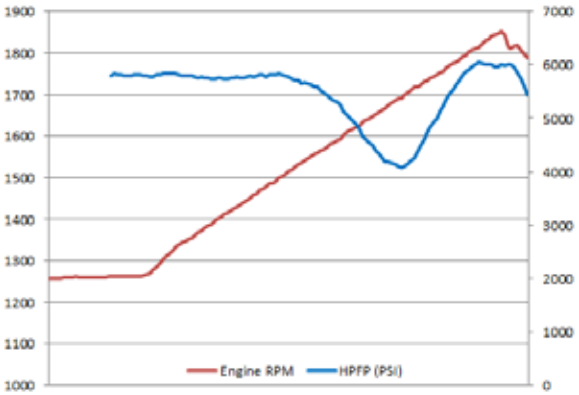
When boost is raised by 1.5psi to 15psi, a 25psi drop in fuel pressure is observed. Notice that compared to the above graph the one below stays closer to 1750 psi.

Stock Car at 15 PSI of Boost

At this level of boost, there is not yet much to be concerned about. An increase of 1.5psi is roughly equivalent to a Stage I setup on a Cobb AccessPort. This small jump in boost pressure gives you more power and should be safe on an otherwise stock car without upgrading the fuel pump.

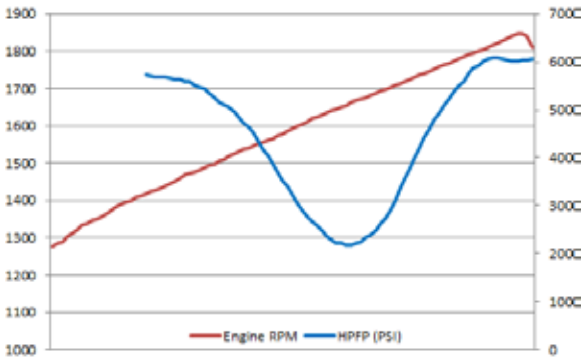
When the boost pressure is raised further to 16psi (+2.5psi over stock) you start to see a dip in fuel pressure that becomes a concern.

Here the limitation of the factory pump is encountered. You can also see that the OEM pump starts to recover around 5000 engine RPM. As the rpms increase the fuel pumps faster, 1.5 times the rate of the engine, and is able to resume meeting the 1700psi set point.



Stock Car at 16 PSI of Boost

Raise the boost over 17psi (+3.5 psi over stock) and fuel pressure becomes dangerously low. This will result in unstable fuel delivery and detonation.



Stock Car at 17 PSI of Boost

Remember this is on an otherwise stock car. Other power modifications, like a downpipe or top mount intercooler, will exacerbate this problem.

Installing a Cobb AccessPort should be accompanied with an upgrade of the fuel pump if you perform any power modifications.

Without an AccessPort it will eventually become necessary to upgrade the fuel pump but a single upgrade like an exhaust or intake will not typically require a fuel pump upgrade.

Before moving on to another key point, it is worth remembering it all boils down to this; when increasing boost more than about 1.5 psi you need to upgrade the fuel pump internals. Cobb AccessPort off-the-shelf maps increase boost. For this reason, you need to upgrade the fuel pump when you have an AccessPort and any other power modifications.

Model Year Differences

The Mazdaspeed6 and 2007-2009 Mazdaspeed3 have open-loop control of air/fuel ratio (AFR) at full throttle. Rather than adjusting AFR real time they use stored information to decide fuel delivery.

For this reason 2006-2009 models can run richer because of the added fuel from a pump upgrade. A custom tune may be required after many power upgrades and increasing the boost via a tuner like the AccessPort.

The 2011-2013 Mazdaspeed3 adjusts fuel at full throttle real time with a closed-loop system. This makes it less likely that custom tuning will be necessary just because the fuel pump has been upgraded.

The 2010 seems to be split. Some cars have the ability to adjust fuel trims at full throttle and some don't.

Limitations of Existing Options

Piston/Sleeve

Increase in piston diameter is closely correlated to pumping volume. There are two approaches on the market to increasing piston diameter.

Some aftermarket designs utilize a straight bore piston. This requires subsequently increasing the diameter of the orifice (seal screw) through which the piston reciprocates.

Picture of APR (Cp-e) Pump

This design requires that the seals are enlarged. This increases sealing surface area which will produce more friction on the piston.

Furthermore, the weight of the piston is higher because the entire piston body is bigger. These types of pumps are usually sold as a complete (rebuilt) pump assembly and are thus significantly more expensive.

Other pump kits increase the piston diameter inside the pumping chamber, but keep the original diameter for the rest shaft. This allows re-use of the factory pump seal screw which results in a lower cost alternative.

Fuel Pump Upgrade Kit

There is one side-effect of note; wear due to uneven side loading of the piston is more likely. There are two ways to combat this. First, the pistons are coated. A properly selected coating can reduce friction and increase surface hardness. Second, the manner in which the spring is retained affects how the wear is distributed, more on that in the next section.

Spring

There are two options on the market for spring rate.

Most fuel pump internal kits reuse the original spring. At the time of this writing the only fuel pump option on the market that utilizes an upgraded spring is from APR.

A stiffer spring allows for improved higher RPM performance and reduced cam wear. It's important that the camshaft bucket and camshaft lobe be in contact at all times for long life. Much like when you increase your camshaft lift or valve size you would want to increase your spring rate, this volume increase can benefit from the same methodology.

Spring Retainer

There are two options for how the spring is kept on the piston assembly.

Of the two options for spring retainer, one is similar to how an engine valve is retained. Manufacturers select this method because it's easier for the end-user to install.

Typical Aftermarket Spring Keeper

The other method is the one chosen by Hitachi. This method of retaining the spring allows the piston to rotate slowly. This effectively spreads wear from side loading around the entire circumference of the piston and sleeve, resulting in longer life.

Hitachi Style Spring Retainer

Installation

Again, there are two approaches on the market. The APR pump comes fully assembled. It doesn't get any easier than that. However, as the reader may already know, this option is much more expensive.

Installation of the fuel pump internals can be problematic. The piston and sleeve have very tight tolerances. Any contamination potentially presents a problem that could result in premature failure of the fuel pump. Hitachi style spring retainers can be tricky to install and can be difficult to remove later.

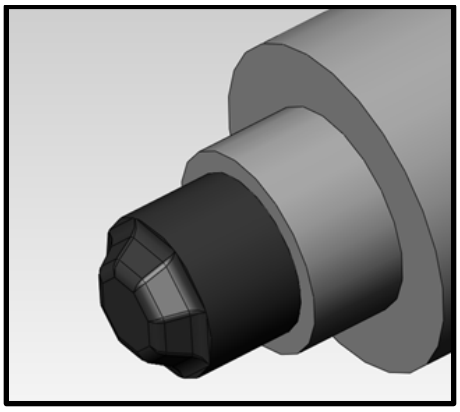
No currently existing pump upgrade option on the market comes with detailed instructions that include removal of the pump from the car through installation of the internals and reinstallation of the pump in the car. Furthermore, no option comes with video instruction nor disclosure of known failure modes.

CorkSport Max Flow Fuel Pump Internals

We set out to design a pump that utilized all of the benefits from the pumps we studied, without any of the inadequacies, cost, or reliability issues with the other options on the market.

Piston

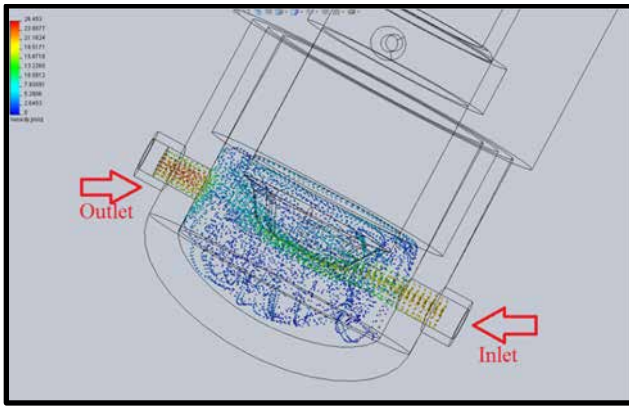
We took what we learned from existing designs and set about to combine some of their best features with an innovative new Computer aided design (CAD) and tested piston head for maximum flow.



CorkSport Max Flow Piston Head

Using CAD, we created dozens of piston head models and ran simulations. A design was found that helps increase flow by directing fuel

towards the outlet of the pump. This design is not the most cost effective from a manufacturing perspective due to the complexity of the piston's multi-angled dome. However, it created the best flowing design.



CAD Simulations of CorkSport Piston

The final design has the best efficiency. Because the shaft of the piston is shorter the assembly ends up 6-10% lighter than other aftermarket options. Less weight means less friction and less force required to change directions. Similar ideas are employed in forged pistons for an engine. Lighter, faster, smoother, better!

The head of the CorkSport piston (blue in the image below) is physically larger than the Autotechs. This helps improve pump capacity in the same manner as increasing the piston diameter.

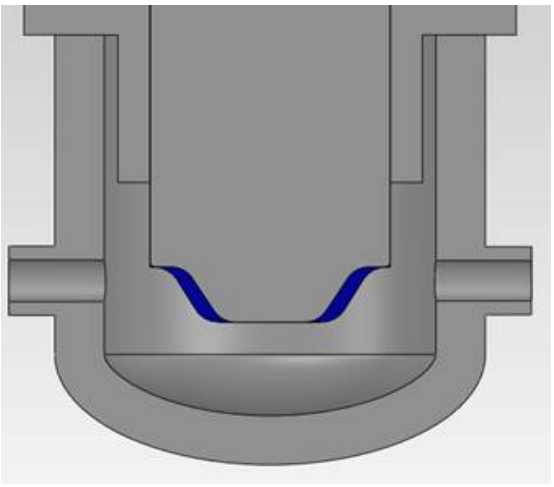


Diagram Showing Volume Difference

Material

Once the piston's shape and design was determined the next step was to decide the material the piston would be made from. Composition and physical hardness of the Hitachi piston was tested to determine how they made a piston that lasts 200,000 miles.

CHEMISTRY

Element	9318-CHM
C[1]	0.70
Cr	0.22
Mn	0.40
Si	0.25
P	0.015
S[1]	0.002
Ni	0.16
Mo	0.53
Cu	0.05
V	0.29
W	0.04
Fe	Balance

Composition Analysis of Hitachi Piston

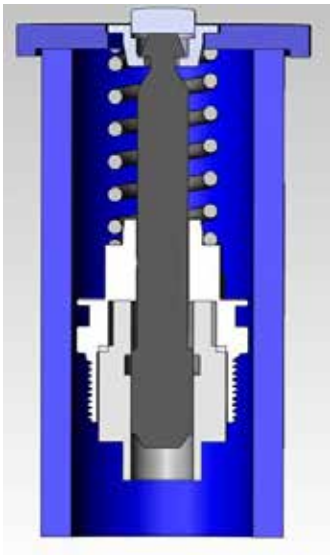
The hardness test showed the core of the piston was not as hard as the surface. This is because the piston goes through a hardening process. This hardening precludes the need for a coating of the factory piston.

VICKERS MICROINDENTATION HARDNESS

Laboratory Number	Depth from Surface (in.)	HV$_{100}$[1]	HRC Equiv.[1]
9318-HRX	Core	730	62
	0.003	842	69

Hardness Testing of Hitachi Piston

A similar metal as the factory piston was selected for the CorkSport internals and then hardened in a similar manner. This alone will provide OEM or better life expectancy. The CorkSport piston goes a step further in that it also has a coating to reduce friction.



Install Tools

The above picture shows the two components of the included tool set in blue.

Spring

In a perfect world, an increase in flow would be supported with a stiffer spring for the piston return. The CorkSport internals are the only kit on the market to include one.

Spring Keeper

As mentioned earlier, the factory spring keeper was chosen for a reason. Samples of both style spring retainers were tested to find the right balance between wear and ease of installation.

The CorkSport pump kit retains the OEM style spring retainer for improved performance over the lifetime of the pump.

The Max Flow internals overcome the potential installation challenge of this approach by including an innovative toolset to facilitate installation of the spring retainer.

Coating

With the physical part of the fuel pump design complete attention was turned to other details. A coating is desirable to further protect the piston and decrease friction during operation. After testing dozens of compounds, a very strong coating was selected that is applied with a proprietary PVD process. This process allows for an exceptional bond with the metal, lower static friction, and increases in surface hardness.

Various Coatings Tested

Manufacturing

A very strong alloy was selected for the CorkSport internals. They are then machined to incredible six micron tolerances! These tolerances were then compared favorably to a dozen factory pumps. Any Max Flow internals outside of this strict tolerance are immediately rejected.

To maintain these super-tight tolerances the piston and sleeve must be mated together. To make sure they're paired for life, the piston and sleeve are serialized. This helps to prevent issues and to track the life of the components.

After heat treatment for maximum strength; the coating is applied. This increases overall hardness as well as serves to reduce friction.

Most companies would be well finished at this point but our research has shown that when the coating is applied it is very difficult to maintain the extremely smooth surface. The coating can have many microscopic hills and valleys. In order to correct this, the pistons are then re-machined back to their original six micron tolerance.

CorkSport Internals With 1000's of Miles

Installation:

After all the care to make the best fuel pump upgrade kit on the market it would be a shame to have them fail because of an installation error. Successful installation is supported in three different ways that no other pump option on the market employs.

Tools are included to help you assemble the pump. This allows for the safest installation when coupled with our install videos and installation instructions.

As with all CorkSport products, full color installation instructions are sent with the kit. These include a section with step-by-step instructions as well as a checklist to make sure nothing important is overlooked.

Install videos are provided for removal and reinstallation of the pump in a Mazdaspeed3. Mazdaspeed6 and Cx7 will be very similar. Also, included are all of our lessons learned, aka ways to screw-up installation.

Comparative Benchmarks

The Table in Appendix 2 shows all the popular pump options on the market as well as the factory Hitachi internals in an easy to reference table.

Custom Cobb AccessPort maps have been developed for this pump. Compared to the OTS maps from Cobb, these maps have to take quite a bit of fuel out, especially on the top end.

Conclusion

The CorkSport Max Flow High Pressure Fuel Pump Internals feature:

- Designed Specifically for Mazda's.
- Hardened Surface
- Proprietary coating for exceptional bond with the metal, lower static friction, and higher the surface hardness.
- Lightest design on the market
- Higher rate spring for improved wear efficiency
- Spring Keeper Installation Tools
- Custom AccessPort Fuel map
- Excellent written and video support for successful installation

All of this work adds up to an improved piston volume that is over 8% higher than the Autotech and more than 50% over factory!

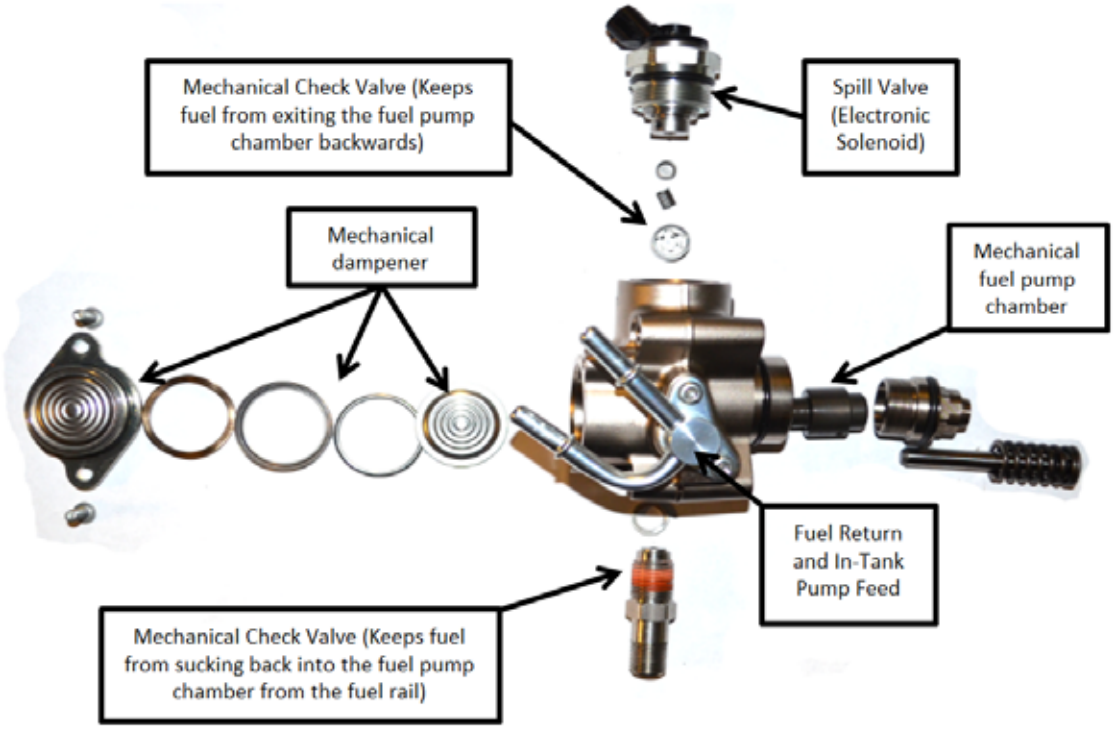
When other pumps start to loose efficiency because of their differences in design or tolerances, the CorkSport internals are just hitting their stride.

That difference in the real world is higher HP numbers, safer air/fuel ratios and the ability to go to even higher power levels without worrying about your fuel supply.

CorkSport Fuel Pump Internals Kit

Appendix I

Exploded View of Hitachi Pump



Appendix II

Fuel Pump Features Comparison

Product Feature	Stock	APR (aka CP-e)	KMD	AutoTech	CorkSport
OEM Spring Keeper	ü	ü	both	û	ü
Upgraded Spring	-	ü	û	û	ü
Large Piston Diameter	- (8.0)	û (9.5)	ü (9.8)	ü (9.8)	ü (9.8)
Octagonal Piston Head	û	û	û	û	ü
Installation Video (Internals)	-	-	û	û	ü
Installation Video (Pump)	-	û	û	û	ü
Install Tool(s)	-	-	ü	-	ü
Lowest Piston Weight	-	û	û	û	ü
Available manufacturer created tunes for Accessport	-	û	û	û	ü
Serialized	û	ü (sticker)	û	ü	ü
Surface Hardening Before Coating	-	ü	ü	?	ü
Machined After Coating	-	?	?	?	ü
Developed on Mazda MZR	ü	û	û	û	ü

Appendix III

CorkSport Internals Breakdown