MM PISTON DESIGN

INTRODUCTION

When a consumer is looking to buy a custom forged piston, they look at price. But, if the top of the piston has some external features, (such as a dome or dish, valve pockets, etc.), the buyer may perceive more value and chose a more expensive piston. In the literary world, this would be like, "judging a book by it's cover".

This study deals with the innovative design of our current pistons. Including hard anodizing, moly skirt coating, skirt cam grind & barrel facing, skirt profiles, skirt thickness and internal milling wall thicknesses. Also, testing piston expansion and skirt flexibility. This article deals with the part of the piston that makes it function properly, but gets overlooked and not understood.

In conclusion, one will come to understand the dramatic gains Metric Mechanic piston's have on engine reliability and acceleration.

"Read and enjoy the pages", Jim C. Rowe, Metric Mechanic Inc.

MM PISTON FEATURE HIGHLIGHTS

- *Low Expansion Forging*
  Forged for high strength with a silicon based 4032 alloy for lower thermal expansion
- *Lightest Piston*
  Full CNC machining of all internal and external surfaces to a specified wall thickness for the highest strength to weight ratio. Resulting in the lightest piston and pin combination for reduced reciprocating mass. Netting improved acceleration and increased engine life.
- *Hard Anodized Protection*
  The piston is fully hard anodized with Moly dry film coated skirts. Hard anodizing is done using electrolysis to form a very hard protective (.002" thick) aluminum oxide thermal barrier that will not come off. It's the 3rd hardest material in the world and it can take 6000°F of heat. The hard anodized thermal barrier is a poor heat conductor and keeps the piston core running cooler. This reduces fatigue and adds to the piston. Hard anodizing the ring grooves, pin bores, and clip grooves prevents them from beating or wearing out.
- *Moly Coated Skirts*
  After the piston is hard anodized the anodizing is machined off the skirt and Moly dry film coating is applied to the skirt to lower cylinder wall friction. Just below the oil ring groove, a small portion of the piston is left uncoated to create a *thermal belt line.* This lowers heat transfer from the hard anodized ring land area to Moly coated skirts.
- *Highest Skirt Flexibility*
  The skirt and strut are shaped for increased skirt flexibility along with a thinner intake (on the low side of the piston) is used to greatly lower and equalize cylinder wall loading.
- *Optimal Skirt Shape*
  The skirt cam grind and barrel facing are optimized for tighter clearance in a performance application without the fear of piston scuffing or seizure.
- *Maximizing Skirt and Pin Oiling*
  5 large 3/16" oil holes to lubricant the skirt. Double grooved pin bore oiling
- *Deeper Valve Pockets*
  Deep valve pockets on the M20 piston so the valves can't hit the piston in the event of a cam belt or tensioner failure. Deeper valve pockets on hydraulic lifter bucket engines. Internal valve pocket reliefs.
- *Ring Land Modifications*
  Anti-detonation grooves added to the top ring land to help atomize fuel along the cylinder wall. Accumulator groove machined into the second ring land to reduce blow by.

METRIC MECHANIC AND WISECO'S LONG TERM RELATIONSHIP

For over 30 years, Metric Mechanic has been using forged pistons made by Wiseco in Mentor, Ohio. We chose Wiseco, because they were only piston company that did in house forgings out of, lower expanding, 4032 aluminum (with 12.2% silicone content). At the time, they did a lot of motorcycle pistons and had just broken into the automotive market. For years, we remained in the motorcycle division, giving us access to some of the best high tech forgings.

Over the years, we have worked with several good sales people at Wiseco. Years later the former production manager at Wiseco worked with Metric Mechanic to write up build specifications for our pistons. After his retirement at Wiseco, our account was turned over to a very knowledgeable seasoned sales person, who has allowed us to fully design our pistons. Without this key person at Wiseco, the execution of this highly advanced state of the art piston would not be possible. We have a very open exchange of ideas and knowledge with Wiseco, backed up by the staff's of both companies.

***All current Metric Mechanic pistons use specifications that have been standardized by MM and Wiseco. The construction and shape of the piston uses mathematical formulas developed by MM. They are based on a multiplication factor of the piston's diameter (and level of boost, when applicable). These specifications and formulas are classified to the two parties.*

PARAMETERS

Over the years, we have seen an increased number of BMW enthusiasts that want a reliable high performance engine for both daily driving and track events (driver's schools). This is a hard piston to design when you consider all the parameters it has to meet. In daily use, the customer won't put up with excessive oil consumption or piston rattle. Yet, when tracked the engine has to be able to run up to 7700 rpm under high loads without piston failure. Even worse, is the daily driver highly boosted (18# to 20#) Forced Induction engine.

So, piston to cylinder wall clearance has to be held to a fairly tight (.0020" to .0025") range. On the other hand, the slightest flaw in piston shape, skirt profile, or skirt thickness can lead to skirt scuffing when attempting to run tighter piston to cylinder wall clearance.
The saying, "The devil is in the details" certainly applies here.

EXPANSION PROBLEM

In an engine, the aluminum piston is expanding at twice the rate of the cast iron cylinder wall. To make matters worse, the combustion (under high load conditions) can heat the piston to twice the temperature of the cylinder wall that is being cooled by the coolant. So, a hot aluminum piston can expand out as much as 4 times greater than the cast iron cylinder wall that it's running against, causing the piston to run too tight in the bore.

When an engine is cold, the piston will have about .002" to .003" positive cylinder wall clearance, but as it warms up the clearance goes away. Under part throttle, a piston will run at a slightly negative -.001" to -.002" cylinder wall clearance. The piston, under high load, can grow to as much as -.003" to -.004" negative clearance. Detonation or pinging (due to poor tuning, low octane fuel, and/or high load) along with excessive frictional drag between the piston skirt and wall can expand the hot piston to -.005" to -.007" negative cylinder wall clearance. At this point, the hot piston will scuff up the skirt, score the cylinder wall and the piston skirt will collapse and the engine will lose power because the piston is starting to lock up or seize in the bore. This condition is termed ***piston seizure***.

A. How silicon affects aluminum expansion

When silicon (very fine particle sand that has a very low expansion rate) is mixed with aluminum the result will be an aluminum alloy with a reduced rate of thermal expansion. The thermal expansion rate of the alloy will be reduced by about the percentage of the silicon in the alloy. So, the expansion rate of a forged piston can be lowered by 12% by using a 4032 silicon based Al alloy with a higher 12.2% silicon content piston over a 2618 copper base Al alloy, with a very low silicone content of .18% silicon. Calculating the difference in silicon content of the two alloys is (12.20% - .18% = 12.02%) about 12%.

All BMW production engines use cast pistons. Cast pistons usually have a silicon content of 16% to 19%. These pistons will have a corresponding lower expansion rate of about 16% to 19% compared to a 2618 forged piston. Adding silicon increases the hardness and wear resistance of the piston. On the down side, cast pistons are more brittle (less ductile) and are more prone to cracking or breaking apart because they are cast with a higher percentage of silicon. A cast piston, because it's formed by pouring hot molten aluminum into a mold, creates a low density and porosity piston that is 40% weaker than a highly compressed dense forged piston. To make up for it's weakness, the cast piston will usually be quit a bit heavier than a well designed forged piston. When an engine spoons up, the reciprocating mass (piston/pin weight) quickly becomes the enemy of an engine's ability to accelerate itself.

The life of an engine is primarily dictated by the compression ring beating out the upper ring groove. For over 30 years, we have used forged pistons made from 4032 (12.2% silicon alloy). We have observed, due to dense/hard ring grooves, an increase in engine life of 2 to 3 times greater than an engine using factory cast piston.

B. The roll of skirt barrel facing and cam grind

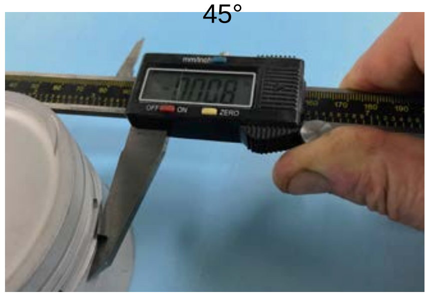
A piston skirt has to have a slightly oval shape, that is flexible, to run in a round cylinder. This is necessary because the hot aluminum piston, heated by the combustion, expands at twice the rate as the cast iron cylinder wall that being cooled by the coolant. The top of the piston is round and about .020" or .5mm smaller than the bore and then tappers out slightly to the oil ring. The piston skirt has a slight horizontal oval shape called ***cam grind***. Vertically, starting just under the oil ring groove, the skirt has a slight diverging tapper (for about 5 to 10mm) that blends into the skirt called ***barrel facing***. The cam grind and barrel facing of the skirt are critical measurements that can dictate how tight a piston can run in a bore.

Cam grind is measured horizontally across the skirt just under the pin bore. Measure the skirt perpendicular to the pin plane, then rotate 45° and measure the skirt again. The amount the skirt drops off is the cam grind at 45°. Move to the pin plane and measure the piston (if the piston is round), this will be the cam grind measurement at 90°. If the piston is not round, double the measurement at 45°. The barrel facing measurement is taken just under the oil ring groove and subtracted from the skirt diameter. ***The photos below show how to measure cam grind and barrel facing on a piston. Shown is a stock S14/S38 Piston.*

Zeroing in the caliper at the bottom of the skirt

Cam grind measurement at 45°. The piston skirt has dropped off .011" or .275mm at 45°

Cam grind measurement at 90°. Here the skirt has dropped off .022" or .55mm @



Measuring of the barrel facing, the drop off just under the oil ring groove, to be .008" or .20mm

C. How skirt strut support dictates the upper limit of piston expansion

When a piston starts to score or seize in a bore, it will usually end up scoring the cylinder wall and piston at the 4 points where the 4 struts support the 2 piston skirts. At these 4 points, the piston skirt is very ridged and will want to stick when it gets in trouble. Usually, the piston will be collapsed .007" (.175mm) or more. In my opinion, the diagonal measurement at these points, where the strut meets the skirt, should be about .008" (.2mm) or more and is more important than the cam grind dimensions, Scoring at these 4 critical points can be reduced by increasing the cam Rgrind of the piston skirt but at the same time the load area of the skirt will be proportionally reduced. Skirt tapper (barrel facing) in the range of .007" (.175mm) just under the oil ring groove is used to prevent scuffing at the upper region of the skirt. Other factors that alter the this critical diagonal measurement of .008" at the skirt strut support are the expansion rate of the aluminum alloy, how much load or rpm the engine will run at and the pistons diameter. The strut measurement can be trusted more than the cam grind measurement because it takes into account different piston shapes such as round, slab. slipper, X , strutted and asymmetrical skirt designs.

For example, if we design two pistons, a slab (outboard strutted) and a strutted (inbound strutted) piston, using the same cam grind of .010" @ 45° and .020" @ 90°, one would think that they would function the same way in a bore. But instead, the strutted piston, with its inbound strutted design will be far more prone to failure (scoring or seizing) than the slab piston and require more cylinder wall clearance. This happens because where the strut meets the skirt on the slab piston is at 40° and will have an .008" skirt drop off; but with the strutted piston design, the strut intersects with the skirt at 20° and the skirt will drop off just half as much or .004". This makes the strutted piston much more prone to scoring or seizing in a cylinder and requiring more cylinder wall clearance

To make the strutted piston drop off .008", where the strut contacts the skirt, will require double the cam grind (or a .020" drop off at 45° and a .040" drop at 90°) to function the same in the bore as the slab piston. The problem with this is now you only have half the load surface of the skirt riding against the cylinder wall. Not good for longevity or keeping the cylinder round. This is a big reason why we favor the slab piston design with outboard skirt strut supports and far greater skirt flexibility.

The more the skirt strut supports are placed inboard, the more prone the piston will be to piston seizure (scoring) because the skirt gets too rigid.

D. Horizontal skirt slit

By cutting a horizontal slit, on the intake side, just under the oil ring groove reduces the temperature of the skirt. The heat from the crown of the piston has to go around the horizontal slit and by the pin boss area to get to the skirt, so, the skirt runs cooler. Also, the skirt is weakened by the slit, making the skirt more flexible. We have been doing this trick to our pistons for over 30 years with great success.

Our current piston on the left has a thinner intake (low load) skirt for greater skirt flexibility over our earlier (horizontal) slitted piston to the right.

E. Increasing skirt flexibility

The skirt needs to have flexibility to keep it from scuffing up in the cylinder. This can be done by machining a horizontal slitting just under the oil ring. But a far better way is by reducing skirt thickness. Especially thinning the intake side, where the skirt sees very little load.

F. Reducing skirt friction

Minimizing friction between the piston skirt and cylinder wall by increasing skirt lubricity.

1. Machining a fine grooved texture in skirt to reduce the surface area dragging against the cylinder wall and to hold oil on the skirt.
2. Adding dry film moly coating (preferably solvent based) to the piston skirt when anodizing is removed from the skirt of a hard anodized piston.
3. Increasing oil to the skirt. Lubing the lower half of the skirt by chamfering the bottom of the skirt. Oiling the top half of the skirt with 5 x 3/16" oil return holes that center at the bottom of the oil ring groove (holes placed half in the oil ring groove and half in the skirt).

G. Hard anodizing for piston protection

For high performance, boosted, or race engines that more than likely will see abuse from detonation or high loads, hard anodizing can often prevent a catastrophic piston failure. Hard anodizing or aluminum oxide is very hard (Rockwell 65c scale), has a low expansion rate, can take 6000°F of heat, is very poor thermal conductor, and can increase the surface lubricity of the piston. Hard anodizing is about like putting a .002" case hardened steel membrane around the piston with out a weight penalty.

A piston skirt that is hard anodized, under normal to hard driving conditions, has more lubricity and the anodizing will not wear off. But, it does have three draw backs; one happens at the start of piston seizure, the other is that the skirt runs hotter, and lastly the core temperature of the piston is more unstable.

If a hard anodized piston gets overheated and/ or is pushed to the point of failure, the hard anodizing (*aluminum oxide*) can get scrubbed off the skirt. *Aluminum oxide is an abrasive used to make sand paper*. So, when the piston starts to fail, the abrasive nature of aluminum oxide causes scoring or galling between the piston skirt and cylinder wall. The aluminum oxide abrasive is then mixed in the oil and circulated throughout the engine. This causes engine clearances to increase quickly.

With a hard anodized piston, the heat from the combustion chamber, stays on the outer anodized surface and transfers into the cylinder wall. Compared to the crown temperature, the skirt of a fully hard anodized piston will see less than a 50°F drop in in temperature. Removing the anodizing from the skirt of a hard anodized piston, will drop the skirt temperature about 150°F. Removing the anodizing from the skirt, allows a pathway for the heat in the piston core to escape to the cylinder wall, for a cooler running piston skirt and core. A lower core temperature lowers piston expansion, increases piston strength (under load), and extends piston life.

The best option, seems to be to remove the hard anodizing from the piston skirt and leave it bare or add a moly dry film coating to the skirt. The moly coating adds lubricity to the skirt and if it wears off, it works with the oil as an additive. When a moly dry film coating is applied to bearing shells, it makes them virtually indestructible. On the other hand, when applied to the skirt of a piston it tends to not hold up so well. But, by making the skirt of the piston more flexible to reduce cylinder wall loading, I feel the potential for a moly dry film coating not to wear off the skirt would be quite good.

Hard anodizing the piston, then removing the anodizing from the skirt, and adding a moly dry film coating to the skirt seem to be the best combination.

This is a current M20 hard anodize MM 3000 Sport piston with deep valve pockets. The entire piston is hard anodize except the skirt. Just under the oil ring groove you'll notice shinny aluminum thermal belt line with 5 large 3/16" oil holes, used to lubricate the textured moly coated skirt.

CAD designing the chamfered 3/16" oil return holes for the MM S52 3200 Sport piston.

Additionally, hard anodizing the ring grooves eliminates micro welding of the compression ring to the ring groove and more importantly can prevent the compression ring from beating out the hardened ring groove. Hard anodizing will protect a piston from abuse and/or detonation better than any other surface treatment. Hard anodizing ring grooves, would virtually never wear out. Instead the rings would wear out before the hard anodized grooves.

H. Minimizing piston rock in a cylinder

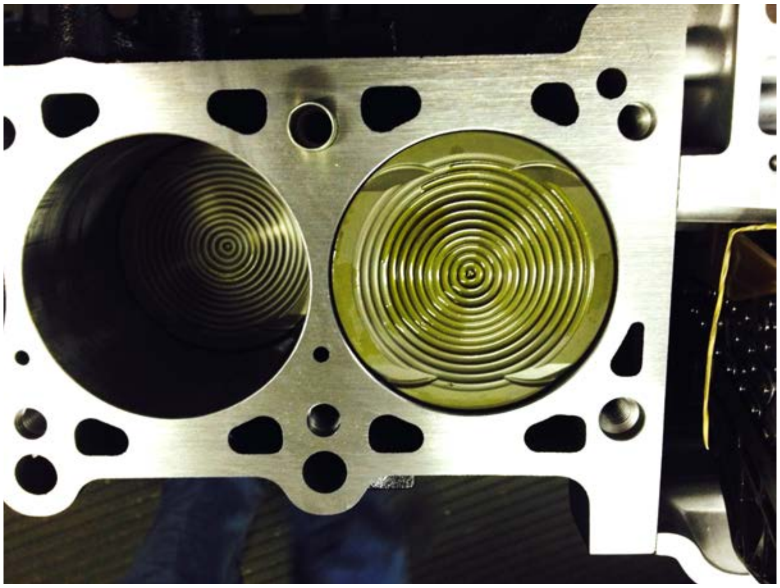
An angular thrust is generated against the piston, by the connecting rod, causing the piston to want to rock in the cylinder. The following ways can be used to stabilize the piston:

1. Holding piston to cylinder wall clearance to a minimum without producing a failure is important in preventing piston rock. Excessive piston rock due to too much cylinder wall clearance can cause the piston to slap and make noise, increase skirt wear, increase oil consumption and/or cause poor ring sealing (blow by).
2. Running piston pin offset, usually 1mm (.040") to the load side of the cylinder (the exhaust side on a BMW), will help reduce piston rock.
3. The piston pivots about the centerline on the piston pin. From the centerline of the pin to the top of the piston (excluding a dome) is called the ***compression height***. The overall height of a piston is about double the compression height of the piston. The higher the piston pin location on the piston, the more stable the piston will run in the bore and the shorter the piston can be made.

I. Boosted Piston Design

All Metric Mechanic Forced Induction engines are specifically designed to take boost. For a forced induction piston to work under boost is has to be designed to take 2 to 3 times the load of a normally aspirated piston. The wall thickness of this piston is mathematically calculated based on piston diameter and level of boost. By use of internal milling to a specified wall thickness, our forced induction pistons will generally weigh only 10% to 15% more than our normally aspirated pistons.

The piston is fully hard anodized (except the moly coated skirts), to form a hard thermal barrier, to protect the aluminum piston core.



MM hard anodized Surface Turbulence (patented) piston top, used to greatly reduce detonation in our boosted Forced Induction engines.

Under compression, the fuel particles in a cylinder are compressed and liquefied by the top of the piston. By incorporating Surface Turbulence ("U" shaped concentric grooves) to the top of the piston, the compressing mixture tumbles and scrubs fuel partials off the top of the piston for a more atomized mix. The higher the state of atomization, the more complete the burn.

TESTING PISTON EXPANSION AND HEAT TRANSFER

The conclusions listed above and below, are based on 35 years of building high performance BMW engines. During this time, we have run expansion tests on OEM BMW cast and forged pistons.

The following is the test procedure. We used a hot plate covered with a 1/4" x 200mm round steel plate and tested one piston at a time. Using an infrared laser beam gun, held horizontally, the temperature of the steel plate, top ring land for the piston crown, and the bottom of the piston skirt are measured. Using a 3" to 4" ten thousands micrometer, the hot piston was measured at the skirt with the crown resting on the hot steel plate at 450°F. All the pistons to be tested were initially measured at 70°F at the skirt. The initial dimension was then subtracted from the hot skirt temperature dimension to calculate how much the piston had expanded.

Testing the expansion rate of various past and present pistons.

Testing Piston Expansion Rate and Heat Transfer		
Piston Description	Expansion at Skirt	Temperature Measured Plate/Crown/Skirt
Stock BMW S52 & S54 cast piston	.0082"	450°F / 390°F / 225°F
MM early 3200 Sport 4032 Slit on intake side	.0118"	450°F / 390°F / 225°F
MM 3200 Rally 4032 Hard Anodized intake slit piston, but with hard anodizing removed from the skirts	.0089"	450°F / 360°F / 250°F
MM 3200 Rally/Sport NEW (current) Hard Anodized 4032 alloy with 5 large oil return holes, thermal belt line, and dry film moly coated skirt Thinner intake skirt	.0086"	450°F / 380°F /310°F

PICKING THE WINNER

The above testing was done 3 to 5 times on each piston. The same tests were done on 95mm pistons with similar results. From the test results, the biggest factor that influences the expansion rate of a piston is the level of silicon in the alloy.

In the past, we have done testing on how much flexing the piston skirt will take before it deforms (won't come back to it's original size) or breaks. This test was done by compressing a piston with pin, using a vice, in the pin plane and measuring the clamping force with a torque wench mounted up to the handle. A cast piston would break rather easily, without much load. The forged 4032 piston would take a much higher load before it would start to deform and would not break. The forged 4032 alloy, with a 12.2% silicon content, seems to be the best compromise between high strength and low expansion.

The winning piston was the stock cast S52 or S54 piston. This was a bit expected because most cast pistons have a 16% to 18% silicon content vs the forged 4032 alloy with a 12.2% content. No forged 2618 (with .18% silicon) alloy pistons were tested due to their 15% higher expansion rate over 4032.

In second place but, not far behind was the MM 3200 Rally 4032 alloy Hard Anodized forged piston with 5 large oil return holes, thinner skirt on the intake side, and the Hard Anodizing removed from the skirt then, dry film moly coated. In the following SKIRT FLEX TEST it was the big winner.

The skirt temperature dropped over 100°F when the Hard Anodizing was removed from the skirt. Also, it was observed that when the pistons were removed from the hot plate, the fully Hard Anodizing pistons took far longer to cool off. Removing the Anodizing from the skirt, gave the heat an escape route and the piston displayed a normal cool down cycle.

By Hard Anodizing the piston crown, lands, and ring grooves; the piston core runs cooler and the ring grooves won't beat out. The only down side is that, the combustion chamber will hold in more heat, since it's not going into the piston. This is evidenced by the plate and the crown temperature being almost the same. Lowering the compression ratio by about .5 to 1.0 point would help normalize combustion temperatures to prevent detonation.

TESTING PISTON SKIRT FLEXIBILITY

Piston skirt flexibility is a subject that I've never heard discussed or tested. For a given slab piston, once the correct cam grind and skirt tapper (barrel facing) are chosen for a given piston; I believe, ***skirt flexibility*** is the single most important factor in being able to run tight piston clearance in a high RPM performance engine.

The key factors influencing piston skirt flexibility are:

1) The outboard location of where the strut meets the skirt
2) Machining a horizontal slit in the skirt just under the oil ring groove (a technique Metric Mechanic has used for over 30 years)
3) Reducing skirt thickness, especially on the intake side, where it can be made 70% of the exhaust skirt thickness

The relationship between the intake and exhaust skirt thickness was derived by measuring the skirt wear area (contact patch) of stock cast BMW pistons. The contact area of the intake skirt measured about 70% of the exhaust skirt. By making the skirt thickness on the intake side 70% of the exhaust, this should help equalize the wear area on both the skirts and create more even cylinder wall loading.

Testing the piston skirt's flexibility was done by using a valve spring tester and a dial bore gauge. The piston was laid on it's side in jaws of the valve spring tester. So, the piston skirts could be squeezed and the amount of applied pressure, in pounds, could be recorded. A dial bore gauge was used to measure how much the skirt was being compressed, in thousands, on the inside diameter of the skirt. The amount of force, in pounds, it took to compress the skirt from .002" on up is shown for different types of 87mm and 95mm pistons. All pistons were measured from an initially collapsed of .0005”.

Testing Piston Skirt Flexibility - 87mm Pistons					
Piston Description	#@ .002"	#@ .003"	#@ .004"	#@ .005"	#@.006"
S52 Stock Cast Piston (Strut width 57mm)	75#	115#	175#	Piston Scuffs	Piston Scuffs
S54 Stock Cast Piston (Strut width 56mm)	95#	145#	190#	Piston Scuffs	Piston Scuffs
MM Rally HA forged slab piston/intake skirt slit (strut width 71mm & 2.5mm, skirt thickness	60#	80#	100#	125#	160#
MM Race HA forged strutted (Strut width 42mm / Skirt thickness Intake 1.52mm & Exhaust 2.33mm)	50#	78#	110#	140#	178#
NEW MM 3200 Sport S52 87mm HA piston w/ Moly coated skirts. Slab design with 2.2mm exhaust & 1.55mm intake skirts	25#	45#	65#	90#	107#

Testing Piston Skirt Flexibility - 95mm Pistons					
Piston Description	#@ .002"	#@ .003"	#@ .004"	#@ .005"	#@.006"
S14/38 stock cast round piston (Half/Strut - width 56.5mm)	42#	72#	100#	130#	165#
Wiseco S14 Slab piston (Strut width 66mm / Skirt thickness 2.70mm)	75#	115#	175#	Piston Scuffs	Piston Scuffs
MM Turbo M1 round Forged HA (Half/Strut - width 65.5mm Skirt thickness 2.90mm)	55#	85#	120#	160#	205# Piston Scuffs
MM S14/38 Rally HA forged Slab piston with slit intake skirt. (Strut width 65.5mm & Skirt thickness 2.5mm)	40#	70#	100#	130#	165#
MM M30 Race HA forged Strutted piston. (Strut width 43.5mm / Skirt Thickness - Intake 1.75mm Exhaust 2.55mm)	90#	135#	190#	Piston Scuffs	Piston Scuffs
NEW MM S14/38 Rally HA Slab forged piston. (Strut width 65.5mm /Skirt thickness Intake 1.92mm & Exhaust 2.55mm)	22#	33#	48#	70#	90#

**Piston scuffing between the piston and cylinder wall occurs at about 200# based on these tests and piston failures we have seen.

THE WINNING PISTON

Moving the skirt strut supports outward improves flexibility. Therefore, a slab piston has more skirt flexibility than a strutted piston. Machining a horizontal slit just under the oil ring groove on the intake (low load) side on an existing piston can greatly reduce cylinder wall loading .

But, the clear winners in this test are the NEW MM slab pistons with 70% thinner intake skirt. This design, reduces cylinder wall loading (friction) by half over our past practice of slitting the intake skirt, the next best piston tested. Adding a Moly dry film coating to the skirts can even further reduce friction against the cylinder wall.

Reducing skirt thickness, especially on the (low load) intake side, proved to be the biggest factor in reducing cylinder wall loading. This can help minimize piston to cylinder wall clearance, lower the piston weight, reduce wear on skirt coatings by lower skirt drag against the bore, keep the cylinder wall more round under high loads and prevent skirt scuffing.

CONSTRUCTING THE ULTIMATE PISTON BY INTERNAL MILLING

A custom forged piston is made from a forged piston blank that best fits the customer's piston description. The blank will be forged from dies to cover a fairly wide range of piston dimensions to hold down the cost of making a custom piston.

A custom piston is full CNC machined on the exterior but on the interior (back side) the piston will be left in it's natural forged shape with limited internal milling to hold down cost. This leaves a lot of dead weight on the piston.

An enlightened different way of thinking is to put the piston on diet by internally machining all the surfaces of the piston to a specified wall thickness. Wall thicknesses specifications were mathematically formulated based on piston diameter. Once these wall thickness formulas and piston specifications were established, the time it took to develop a piston was greatly reduced and simplified.

The net results are, that our current pistons are 10% to 15% lighter than our previous pistons, that were already light for a custom forged piston. Reducing the piston's weight, is the most critical weight savings you can make to an engine's reciprocating mass. Once the piston is made light, then the weight on the piston pin can be reduced along with rod weight.

The biggest weight loses come from early model M10 and M30 engines. To the left, is a MM 2200 Rally piston that is fully machined on the backside for a maximum strength to weight ratio. The 92mm piston weighs just 315g and uses a 89g pin. The "H" beam 143mm rod used with our 2200 Rally piston and weighs 525g.
The 89mm stock 2002tii piston on the right, is a slug at 545g and uses 138g pin. The stock rod is 135mm long and weighs 735g.
This is a weight savings of over a pound!
The piston we use in our MM 3700 Rally engine for a M30 engine has similar gains.

IMPORTANCE OF REDUCING PISTON WEIGHT

Weight is the enemy of acceleration and reliability. The reciprocating mass in an engine is alway accelerating and decelerating (the starting and stoping movement of the piston and rod). To make matters worse, the reciprocating mass squares with distance (out from the centerline of the crankshaft) and rpm (revolutions per minute). Therefore, the weight of piston (furthest from the crank) is the most important, followed by the piston pin and the small end of the connecting rod.

Destructive nature of RPM vibration

At about 6000 to 7000 rpm most BMW engines will start to vibrate due the starting and stopping of the reciprocating mass (piston, pin and small end of the rod). This has nothing to do with an engine being out of balance. If an engine is stroked or gets a displacement increase, the point of vibration will occur earlier. This vibration has a slow damning effect on reliability. On the external side of the engine this vibration will look rather innocent, causing accessories or hardware (nuts and bolt) to come loose or fall off. Or more serious problems such as flywheel and harmonic balancer bolts to come loose. Internally, it can cause a rod bolt to vibrate loose (leading to a rod failure), an oil pump sprocket nut to fall off, and/or a crankshaft to metal fatigue and break. The lighter the piston/pin and (to a lesser extent) the rod can be made, without sacrificing reliability, the high the engine will rev before it vibrates. Less vibration equates to less fatigue and greater reliability. In the last two decades, due to the efforts of lighting the piston and pin, MM Rally or MM races engine have been steady increasing in power and have about 3 times greater life. With our current lighter internally milled pistons, performance and longevity should be even greater. Power and reliability at a far lower long term cost, usually don't go together. What a deal.

Internal milling

By using extensive internal milling, to the backside of the piston, excessive material can be removed to produce a far lighter piston without sacrificing strength. Even though these milling operations add to the cost of the piston, they are worth it. Given the weight loss, added reliability, reduced cylinder wall loading and performance advantage over a typical forged piston. These are very big important gains!

The NEW MM piston was mathematically formulated for a maximum strength to weight ratio. Machining operations were made to the skirt/strut thickness, skirt tapper (barrel facing), skirt cam grind (oval skirt shape), crown thickness, arched pin boss & wall thickness and thickness behind the ring grooves. Reducing the weight of the reciprocating mass is by far the biggest gainer in the engine's ability to accelerate itself and will make an engine spool up quicker.

The following chart compares the weight of a BMW stock cast piston to an earlier MM forged piston and the currently NEW redesigned MM forged piston. The weight of the accompanying pin is also shown. Along with the combined weight in parentheses.

Comparison of Piston Weights			
Piston Description	**BMW Cast Piston** **Piston/pin weight in grams (Combined weight in grams)	**Early MM Forged Piston** **Piston/pin weight in grams (Combined weight in grams)	**Current MM Forged Piston (w/ internal milling)** **Piston/pin weight in grams (Combined weight in grams)
S54 / E46 M3	365g / 99g (464g)	—	272g / 85g (357g)
S52 / E36 M3	315g / 109g (424g)	310g / 89g (399g)	264g / 71g (335g)
M20 / E30 / 325i	372g / 109g (481g)	330g / 89g (429g)	251g / 71g (322g)
S14/38 M5/6	445g / 120g (563g)	362g / 89g (451g)	322g / 89g (411g)
M10 / 2002tii	545g / 138g (683g)	350g / 89g (439g)	315g / 89g (404g)

Piston evolution: The piston on the far right is a BMW stock cast S14/S38 piston. The center piston is an earlier MM Forged piston with some internal milling done. The piston on the left, is our current state of the art piston, that is completely machined on the backside. Then, the piston is fully hard anodize, except the skirts that are moly dry film coated. Our Rally S14/S38 piston and rod assembly weighs 960 grams compared to 1375 grams for a stock M engine. This is close to a one pound weight lose! This gets ride of the annoying vibration in the first generation E30/S14 M3 engine.

Going from a stock cast piston/pin to the NEW current MM forged piston/pin design, represents a 20% to 40% weight loss in reciprocating mass and about a 10% to 20% weight reduction over our earlier forged piston/pin set up. Huge gains!

Developer - Jim C. Rowe
Life is good!
Metric Mechanic Inc.