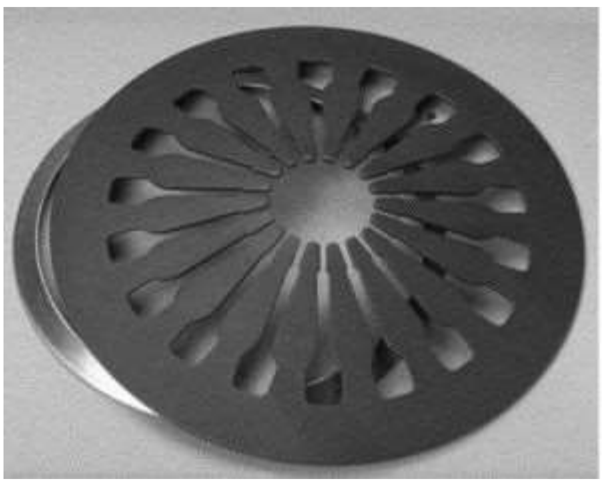
Background, yes I'm at it again.

As some of you know I've been heavily involved with the Dao of the Beta clutch and trying to improve its performance for some time. In the time of this exploration the trials world (not Beta weirdly) has moved on to a different type of clutch and because I'm always striving to understand how things work, I started wondering what is it about the diaphragm clutch that has made it the darling of the trials world. Much has been written about this magic thing but I've never seen an adequate explanation about why this clutch has become the reference to which all trials clutches are judged. What is the mojo that has allowed the diaphragm clutch to displace the coil spring clutch. It may surprise you to know (surprised me but it shouldn't as I have the old Subaru clutch in the garage) that the diaphragm clutch has been the standard in automobiles for decades.

What makes a diaphragm clutch a diaphragm clutch?

Simply put it is a diaphragm spring! Also known as a Belleville washer.



As opposed to the common coil spring the diaphragm spring is a conical shaped washer that is flexed, typically flattened, by applying a differential pressure to the inside radius relative to the outside radius. So, what's the big deal? A spring is a spring, right? Well not exactly. The magic of the diaphragm spring is in its deflection curve. A coil spring is linear. To squish a 2kg/mm coil spring 1mm you have to apply 2kg of force. To squish it 2mm requires 4kg, 3mm needs 6kg and so on. A straight line right up to either coil binding or material fatigue, whichever comes first. The diaphragm spring is different. Very different. Initially the deflection curve looks a lot like the coil spring, roughly linear, but something happens as the diaphragm spring approaches flat. The force needed to compress the spring flattens out and can, with the proper design, be made to lessen. This is the key to the behavior of the diaphragm clutch. If you care to get into the physics of the thing… [Physik_E (23.12.02) (haussermann.com)]

Let's think about how that affects the operation of a trials clutch.

There are some universal requirements to a trials clutch. First it must transmit power without slipping when it is engaged. Second it must not transmit power when it is disengaged. Third it must be able to be actuated without requiring the finger strength of a gorilla. A possible fourth is the characteristic of how the clutch transitions between the first and second requirements and this is a variable because experts tend to like a light switch clutch to do their acrobatics while us mere mortals like a progressive engagement to keep from getting blasted into the weeds.

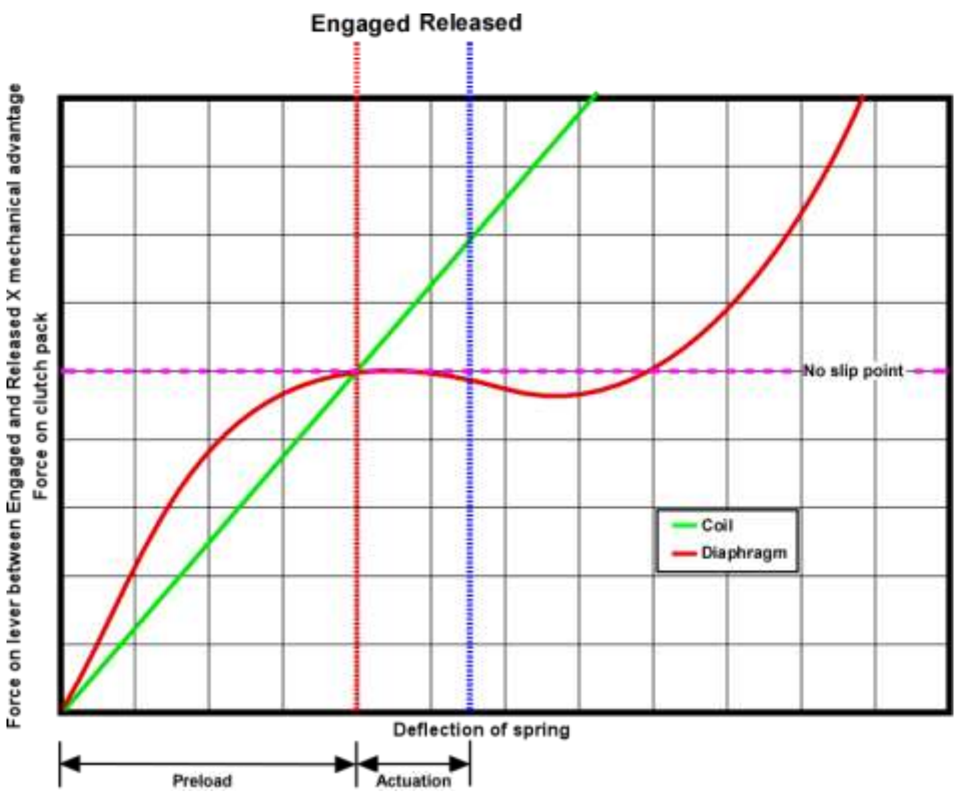
In simple terms the clutch provides friction between two sliding surfaces when they are pushed together. For the sake of simplicity, consider an automotive clutch for a manual transmission using a single pressure plate and a single friction plate. The two plates are held together by the pressure of a spring and pushed apart by a throw-out bearing. When engaged this clutch has to be able to transmit all the engine power plus any shock loading through the drivetrain (from hitting bumps and going up inclines for example) without slipping. This is referred to as the "torque capacity". The factors that determine the torque capacity are the clamping force of the pressure plate, the coefficient of friction of the disc material and the contact area of the friction surfaces. For a single plate automotive clutch this is a fairly easy calculation. An excellent explanation is here if you're bored and can't go riding.

[How to calculate clutch torque – x-engineer.org]()

So, there are three easy ways to increase the torque capacity on a trials bike. We can crank up the spring pressure to increase clamping force but then we run into the problem of lever pull. We can increase the surface area but we are limited in size of the clutch. To stuff as much surface area into a small space we stack multiple plates in a clutch pack. The standard Beta clutch pack has six friction plates and five steel plates giving us twelve friction surfaces (includes the two aluminum surfaces on the pressure plate and the hub base). The third method is to change the friction material to one that has a higher coefficient of friction. The problem with this method is the feel of the engagement tends to be very on/off. Not to mention fancy friction material tends to cost more than your basic cheapo cork-based material. Still there are options such as Kevlar which is used on some off-road clutches.

So, what does this have to do with the diaphragm clutch?

The graph shows how this all plays out. Let's call the torque capacity the "no slip" point. If we assume the no slip point is the same for both clutch packs (it's not but I'll get into that later) than we can see the effect the diaphragm transfer function has on the lever pull relative to the coil spring. Here we can directly compare the displacement vs force curves for a coil spring vs a diaphragm spring. The line marked "Engaged" is with the lever out and the clutch pack compressed by spring pressure. The applied pressure on the clutch pack at the "Engaged" line has to be above the no slip point. Everything before the "Engaged" line is preload so the different curve before will not be experienced by the rider. Between the "Engaged" and the "Released" line is where the lever is pulled in. For the coil spring clutch the force required to pull the lever increases linearly as the hydraulics further compress the springs to pull the pressure plate off the clutch pack. The diaphragm spring does something different. Because it fundamentally changes its geometry as it approaches flatness the force needed to compress the spring responds in a non-linear fashion and depending on the design of the spring can actually be less when the lever is fully pulled in. So, the major difference becomes the lighter pull of a diaphragm spring at full displacement of the pressure plate. On the coil spring clutch the force required to fully pull the lever is inextricably tied to the spring preload required to prevent slip, the displacement of the pressure plate and the mechanical advantage of the hydraulics. That relationship is no longer as clear cut with a diaphragm spring clutch.



The payoff?

So now we have been freed from the tyranny of the coil spring's linear transfer curve. How does that change the design options for the clutch? One thing anyone who looked at the design of a diaphragm clutch knows is they use fewer plates. Most diaphragm designs use three friction plates, half of the typical coil spring clutch. How can you get away with fewer plates? Remember the three variables for torque capacity. The answer is you're trading surface area for pressure on the clutch pack. In the graph below using the same curves as before but moving the preload up on the diaphragm spring to apply the necessary pressure to prevent slip with a three-plate clutch pack you can see that the amount of force on the lever required to hold the clutch disengaged is still a bit less than for the equivalent six-plate coil spring clutch. Riders used to the feel of a coil spring clutch often note there is a slight difference in the feel of the diaphragm clutch but they adjust fairly quickly.

Why do diaphragm clutches have less drag?

Another advantage to fewer plates in the clutch pack. Like the torque converter in an automatic transmission, spinning surfaces moving past each other in a viscous fluid will transmit some torque across the gap between them. The clutch pack is no different and though the amount of drag is much less than an automotive torque converter it is still there. This is why when the gearbox oil is cold there is more clutch drag than when the engine heats up and why thinner oil has less drag. Fewer surfaces moving past each other will also experience less of this hydraulic drag but another factor may have to do with an increase in available free play. If a six-plate clutch like the Beta has 1.27mm of throw-out travel that means there is 1.27mm of space to distribute between all twelve friction surfaces averaging out to 0.105mm per surface. (Yes, I know it won't be that evenly distributed but work with me here on this mental experiment) Use that same throw-out displacement for a three-plate clutch pack with six friction surfaces and now there is 0.211mm spacing per surface. Not surprising there is significantly less drag. (Look up laminar flow in viscous fluids if you have a couple hours to waste) This even gives some leeway to increase the leverage of the hydraulic system decreasing throw, reducing lever pull and still have more clearance between friction surfaces.

Downside to the diaphragm clutch?

As with any fine-tuned machine the diaphragm clutch is going to be sensitive to adjustment. Since the diaphragm spring has a "sweet spot" in its displacement curve it's important that the entire mechanism be tuned around that part of the displacement curve. Coil springs allow you to be sloppy in how you tune the system because they don't care where they are on their displacement curve and the penalty for mis-adjustment is heavy lever pull, drag or slippage that can easily be tweaked. Simple spacers can make a huge difference to a coil spring clutch but changing the fundamental behavior of a diaphragm clutch usually involves changing the spring and re-tuning the rest of the mechanism to optimize the displacement. Fortunately, that almost always involves getting the preload right and once set it need not be adjusted again as long as the spring doesn't suffer from mechanical fatigue.