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As a supplement to my whitepaper on the Torque Tube Vibration damper (I suggest reading it first), the following covers the design and function of the Engine Mounts (EMs) and Transaxle Mounts (TMs). The math and terminology is identical to the TT whitepaper, thus I won't reiterate it here.

The EMs/TMs (*mounts*) are basically Vibration Isolators designed to support the weight of the drivetrain, maintain its location within the chassis, and reduce the level of vibration transferred from the drivetrain to the chassis. Compliance is also needed to allow for dimensional changes due to temperature variations and the use of materials with differing CTEs (Thermal Expansion Coefficient). To accomplish this, the *mounts* employ a traditional spring/mass/damper design; this system is not unlike the coil-overs used in the suspension.

So how does a Vibration Isolator (Vi) work and behave? Like all things, a Vi has a resonant frequency (Fn) at which it will vibrate when subjected to something that excites it (i.e. force or vibration input). As the frequency of the input moves away from the isolator Fn, the isolator starts to attenuate (reduce) the amount of vibration transferred out of the isolator as compared to the input, thus *isolates* the output. As shown below, Transmissibility (T - which is the output/input) starts to reduce to below 1 (Output< Input) as the frequency ratio R (input frequency/isolator resonant frequency) increases. At frequencies sufficiently above the isolator Fn, the isolator reduces vibration output vs. the input.

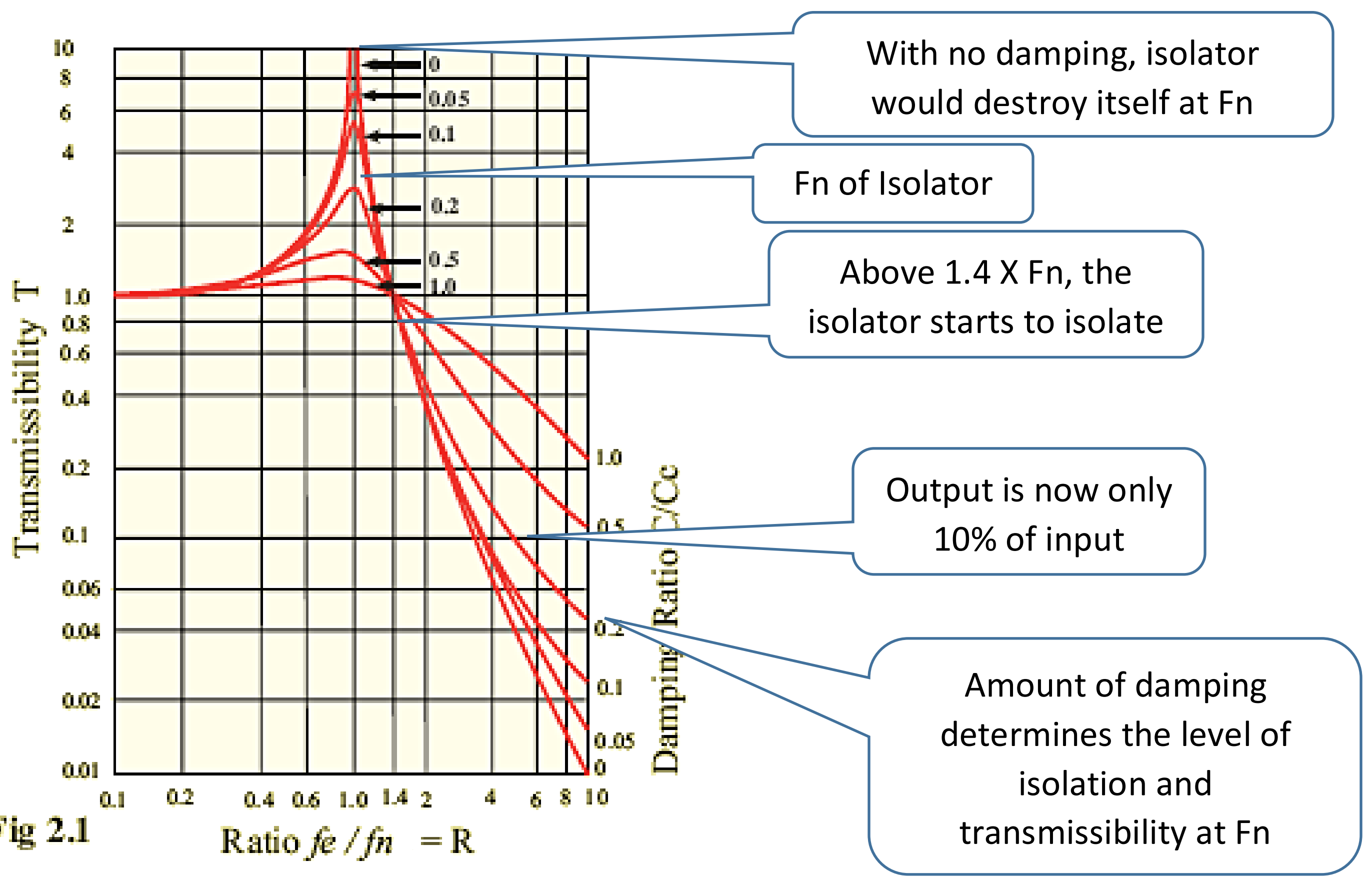


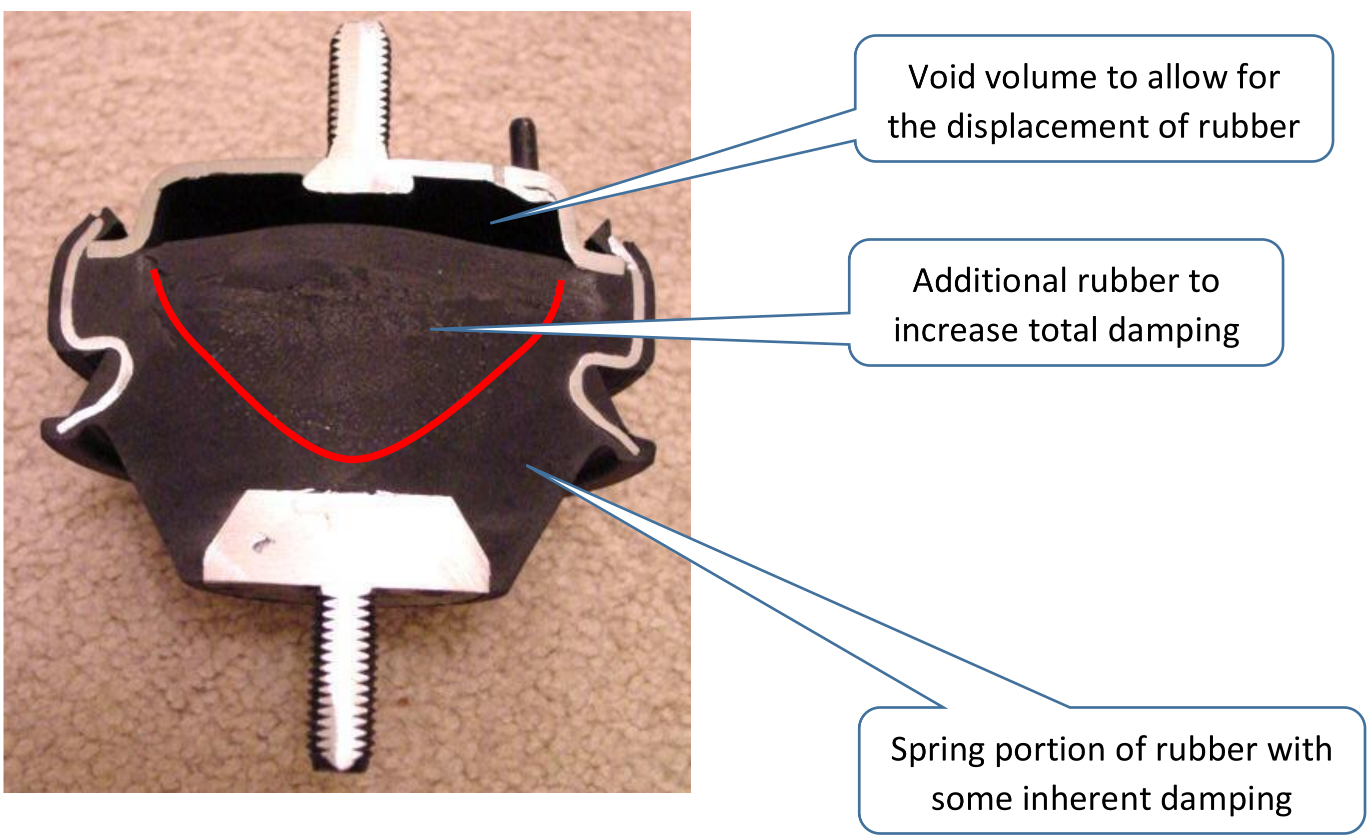
Fig 2.1

The curve above also shows the impact of damping. An isolator with no damping (damping ratio of zero) will wildly resonate and fail at its Fn, but will also significantly attenuate above Fn (attenuation actually starts at Fn X 1.4). As the curves show, if you increase damping, you reduce the transmissibility at Fn, but also reduce the amount of attenuation above Fn. Thus, specifying the amount damping becomes a balance of both resonance “craziness” and attenuation.

The ideal way to resolve the isolator Fn craziness is to never subject it to conditions that will excite it at its Fn in the first place. Design the isolator such that its Fn is below the operational vibration frequency range of the system, so you never have to deal with the Fn. For example, If your drivetrain generates vibration between 10Hz (cycle/sec – 600RPM) and 110Hz (6600RPM), design your isolator to have an Fn of say 5 Hz; thus, at 5Hz X 1.4 (=7Hz) the isolator will always be attenuating engine vibration, yet will not resonate at its own Fn, because it won’t be exposed to any vibration at a low enough frequency to excite it. Thus, under normal conditions, properly designed EMs are never exposed to an input that will excite them and are always attenuating engine vibration. However, there is an *abnormal* condition that does indeed excite them.

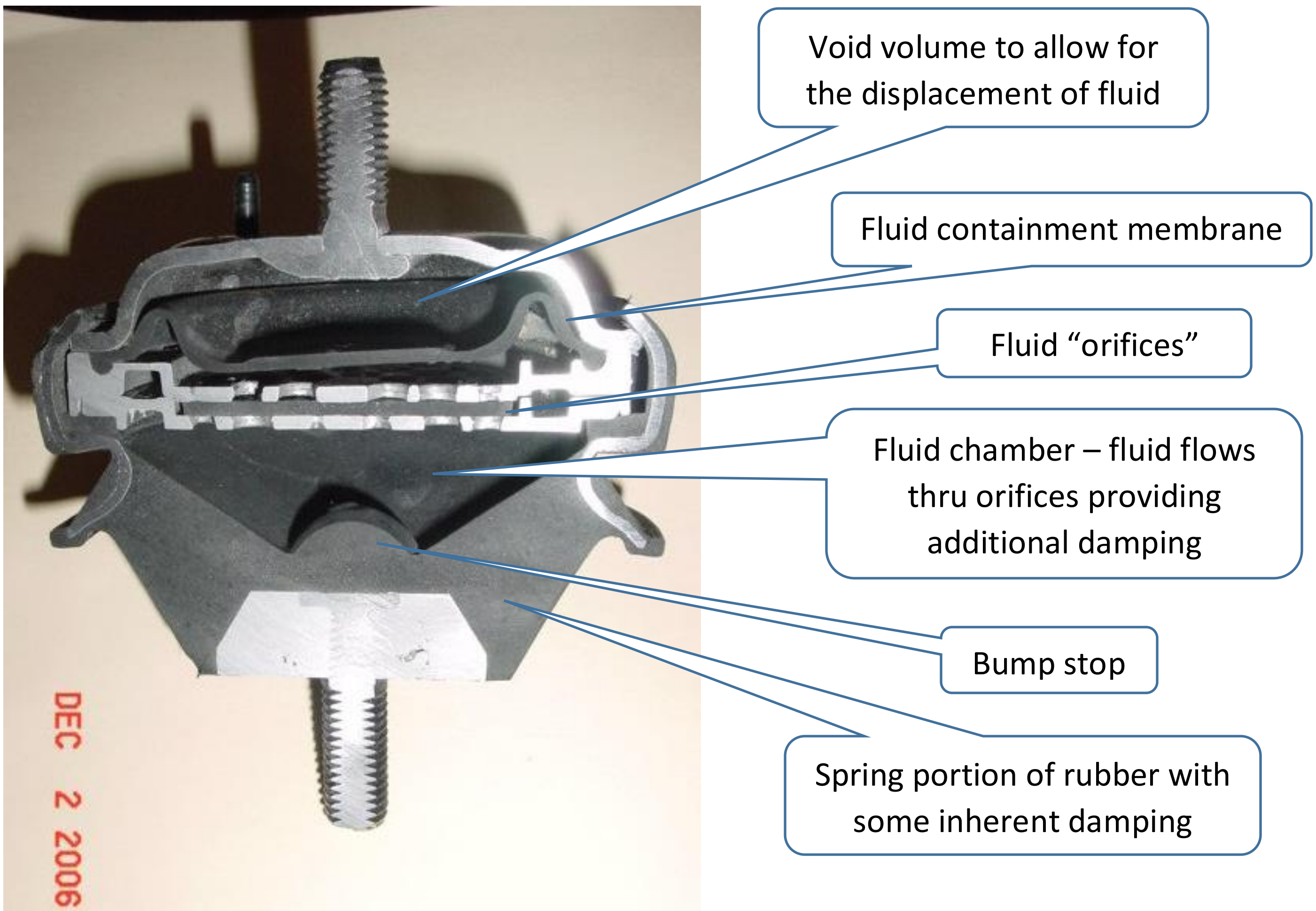
When you start and shut down your engine, RPMs pass between idle speed and zero – somewhere in this range lies the EM Fn; passing thru this Fn is why you see the engine moving for a short period of time upon startup/shut down - It’s the EMs resonating wildly at their Fn which is causing this motion. Imagine if the EM Fn was the same as the idle speed – I would tear itself apart very quickly. So, if you decide to develop your own EM/TM, or specify a substitute, you need to insure its FN is outside the normal operational vibration range, and that it is able to do the other things the OEM mounts have to do, support the weight, are dimensionally compatible, attenuate sufficiently, etc.

Cross section of Ford EM shown below (Roger’s picture).



From the cross section above, you can envision the portion of the rubber which is acting as the spring – the part that is mechanically held/supported from 2 sides. Rubber has both spring and damping properties, and it appears that additional damping was required, so material was added in the middle which increases damping without impacting stiffness much. Is the Ford EM a substitute for the OEM? As long as the Fn is low enough and it is structurally and dimensionally compatible with the OEM design, it will work. Being a solid rubber design, locking down the damping characteristics is not easy, especially since these properties within rubber will also vary with temperature. Thus, it may not be as effective in attenuating vibration over temperature as the OEM design will, but, without side by side testing, no one can know for sure.

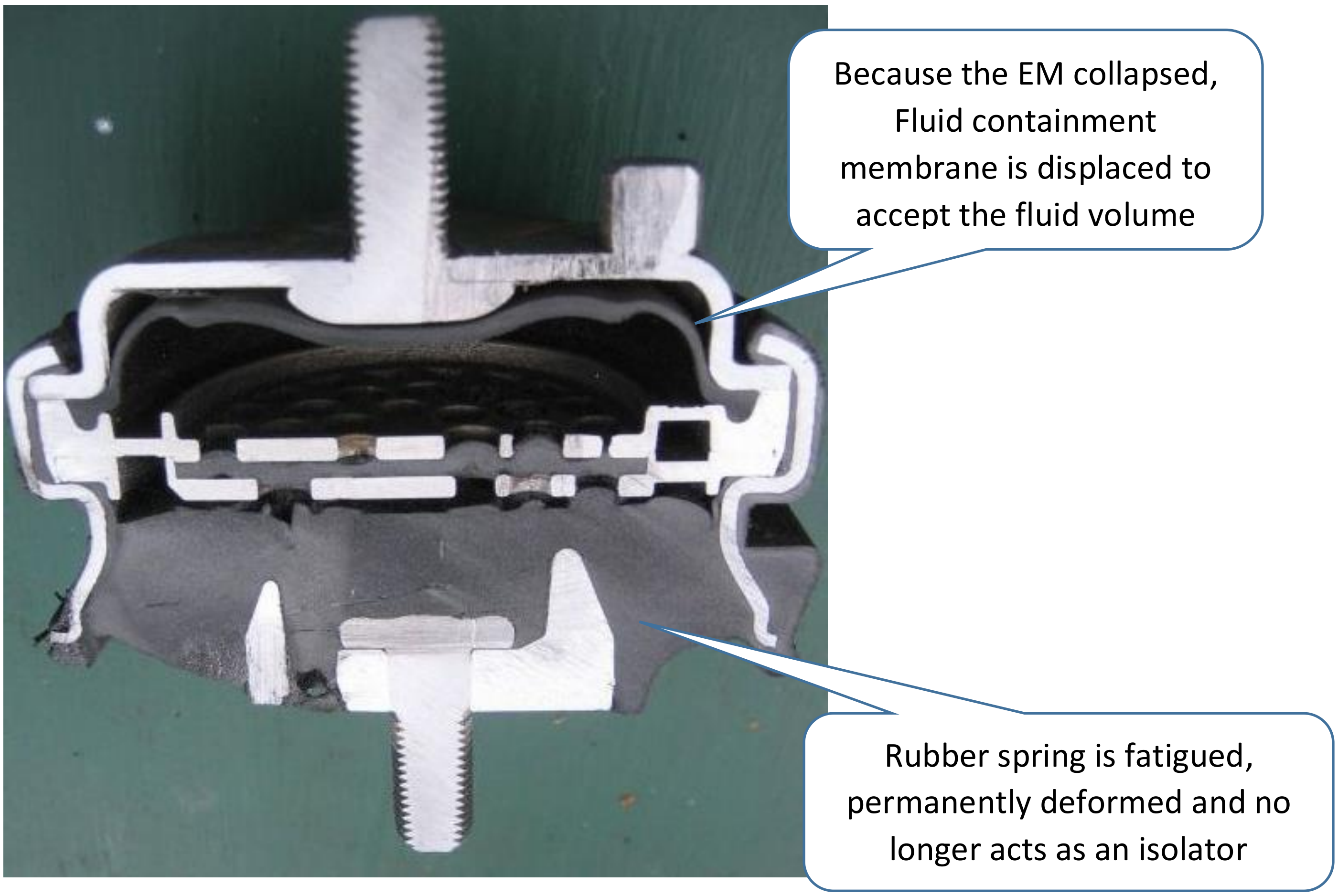
Cross section of Volvo Hydraulic EM shown below (Roger's picture).



The Volvo mount performs the same function the Ford mount, but does it in a more elegant way. They both use the outer rubber perimeter as the spring in the spring/mass/damper isolator system; the rubber also provides the structural connection which supports and locates the drivetrain. Where the Volvo EM parts company is that it supplements the difficult to manage rubber damping (in the spring) with hydraulic damping. As the isolator moves axially during exposure to vibration, fluid contained within moves back and forth slightly between the upper and lower chambers, passing thru the fluid orifices. This causes the fluid to shear absorbing/damping the vibration energy, converting it to heat, just like a suspension shock absorber does. The void volume at the top is crucial to provide a space for the fluid to occupy, especially when the EM resonates at its Fn during engine startup/shutdown. The fluid, being incompressible, would have no place to go without this space.

The damping characteristic of this design are a lot easier to control vs. the solid rubber design. Just changing the fluid viscosity, and/or orifice size, design & quantity will yield differing results. The Hydraulic design is much easier to optimize and, because the fluid properties are more consistent with temperature variations, yield more repeatable performance over temperature. A more elegant design.

Cross section of a collapsed OEM Porsche Hydraulic EM shown below (Roger's picture).



As you can see, the OEM Porsche design is basically the same as the Volvo design. Interestingly, it does not employ a bump stop like the Volvo part – perhaps the Volvo mount is newer/more advanced design? BTW, I can almost guarantee you neither Porsche nor Volvo designed their mounts. They were designed by an isolator manufacturer (specialist) either to meet a specification the automakers provided, or a specification they themselves created based on industry needs. In fact, the automakers may have selected an existing, off the shelf mount that just happened to meet their drivetrain weight requirements. Is the Volvo mount an acceptable replacement for the OEM? Anecdotal evidence indicates it is, so I replaced the collapsed OEM mounts on my '87 S4 with the Volvo EMs almost 2 years ago. Are the properties identical? Probably not – I suspect the spring rates and damping ratio are not exactly the same, but ultimately, they both do a similar thing the same way. I know the Volvo Fn is sufficiently low, as my engine doesn't resonate wildly at idle; beyond that, the nature of the all Vi is to attenuate vibration. Perhaps the Volvo EM is even better at it? Without testing, we can't know definitively. Fact is, even the OEM mount performance can vary due to size and material tolerances.

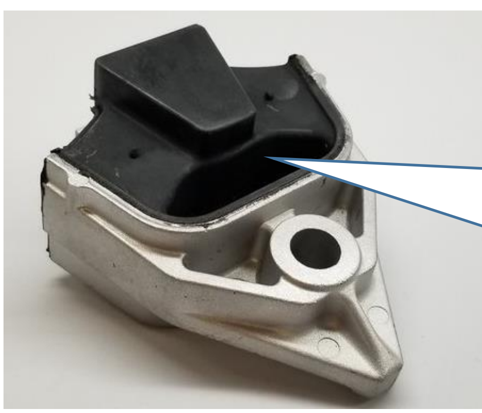
So, what made the OEM EM collapse? It wasn't due to fluid leaking – the fluid doesn't support the weight – it was fatigue in the rubber "spring". After enough stress cycles, the rubber begins to weaken such that it can no longer hold up the drivetrain load and eventually collapses. Most likely, the EM Fn also changes as the mount starts to fail – I suspect it gets stiffer, thus increasing the Fn closer to that of the engine idle speed, which makes the collapsed mounts even more noticeable in terms of NVH.

Transaxle mounts – collapsed OEM and custom molded (picture from Waldo928)

Filling in void makes isolator too stiff, not allowing for displacement

The OEM TMs are similar to the Ford EMs, as they perform the same function relying on the internal damping of the rubber exclusively (no hydraulic damping). The void area in the rubber is critical to keep the stiffness low enough and to allow for the large displacements that occur the brief time the mount is operating at its Fn. If filled in like the custom mount shown, the stiffness is increased significantly, most likely placing the Fn within the operating frequency range – a recipe for poor isolation performance and rapid failure. Another custom aftermarket TM solution is being offered. Is it the same as OEM? Probably not exactly, but like the Volvo mount it is most likely similar enough to act as a more cost effective replacement, especially in comparison to failed OEM TMs. I'm planning on ordering a pair.

New custom aftermarket Transaxle Mount (picture from 928SRUS website)



Isolation properties determined by the properties of the rubber, which, hopefully, are similar to the OEM. Unless the properties are way, way off, I suspect these will perform better than collapsed OEM mounts, perhaps as good as new OEM mounts?