May 2007

Lotus 7 - Clutch Nightmare

A Lotus 7 fitted with a twin cam engine was presented for remedial work to solve a problem where the gearbox occasionally jumped out of gear. What started out as a simple request soon developed into a nightmare.

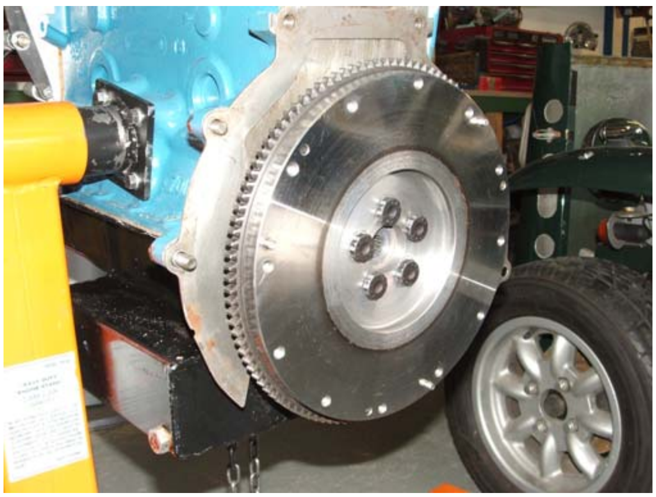
The gearbox was subsequently removed, repaired and then re-installed. The test drive revealed the vehicle had other problems. A broken engine mounting bracket, bell housing rubbing on the chassis, exhaust system rubbing on the body and an engine that lacked power. The engine was investigated and soon a growing list of problems emerged. A leak-down test showed the engine was running on two and half cylinders. The valve springs were so weak they could be depressed with your thumb! There was 0.010” to 0.020” cam follower to sleeve clearance in the cylinder head. Tappet shims had rounded faces and additional brass foil to provide fine adjustment. The brass foil had holes punched right the way through by the hardened steel tappet shim underneath. The cylinder head was removed only to reveal unwanted scores in number 2 and number 4 cylinder bores. Number 4 cylinder had a witness mark at the back of the block which indicated the gudgeon pin had come lose and cut two vertical grooves in the bore. The cylinder head was dismantled to reveal there were major problems with non-standard valves, non-standard cam bearings, worn valve guides and re-profiled camshafts with a base circle of 0.938”. A decision was made to completely rebuild the engine. This process uncovered many other faults which included the cam tunnels that had been over machined moving the valve seats too close to the camshaft centre-line. Other gremlins emerged where the crankshaft centre thrust bearing had failed in a catastrophic way and had damaged the location groove. Some “genius” had tried to solve this problem by fastening a bronze crescent to the centre main bearing cap. This is an unsatisfactory “repair” as the bolted cap is subjected to an axial load of approximately 1200lbs (diaphragm clamping pressure) being applied every time the clutch is operated. This problem was finally solved by re-machining the block to create a location step and installing a custom (wider) thrust washer. During this process, it was discovered that the centre main bearing cap was not square to the crankshaft centre line. A decision was made to fit steel main bearing caps to rectify this problem.

Initial problem

The clutch problem manifested itself only after both engine and gearbox were rebuilt, and then subsequently installed back into the vehicle. When starting the engine and attempting to select any gear it was discovered that it was impossible to do so. Starting the engine when in gear and clutch pedal depressed, made the vehicle jump forward. This action reinforced the diagnosis of a faulty clutch and or gearbox input shaft problem.

Investigating the problem

After removing the engine gearbox from the vehicle, this allowed a more detailed examination of all the components. The clue to this particular problem was a narrow 6mm wide heat band that can be clearly seen on the photograph of flywheel friction surface.



During normal operation, the clutch friction pad would contact the full width of the material without showing signs of over heating. To better understand this fault, see the clutch diagram on page 7.

A number of attempts were made to diagnose the problem whilst the engine and gearbox were still in the vehicle. This included installing 0.120" (3mm) hardened and ground washers between the engine block and bell housing. Despite moving the engine and gearbox apart by 0.120”, this did not prevent the clutch driven plate from bottoming out in the gearbox input shaft splines.

It should also be mentioned; no resistance was felt or detected when the bell housing was offered up to the engine/flywheel and clutch assembly. Any resistance would suggest the clutch friction plate had bottomed out on the input shaft spline. The bell housing slid easily into position and the fixing bolts were wound in by hand until finger tight.

Building up an accurate picture of the problem was essential to understanding why both the gearbox and engine have suffered extensive wear and subsequent damage. This could only be achieved by adopting a logical approach where every component was assumed to be causing or contributing to the problem. The only way forward was to measure and cross-check all the components that were inter-related from the back of the cylinder block to the gearbox input shaft.

Cylinder block to bell housing alignment

The crankshaft and gearbox input shaft need to be on the same axis or centre line for the two components to operate correctly. If either of these items is off centre then the gearbox input shaft will tend to bind up in the spigot bearing located in the end of the crankshaft. Common problems that cause this are cylinder blocks being machined incorrectly. This is where the crankshaft centre main tunnel is line bored when installing steel caps. Occasionally excessive material is removed in the block tunnel which in turn moves the crankshaft centre line up closer to the top of the block. A similar problem is caused by missing or badly fitting dowels which are located between the cylinder block and bell housing. These are normally recessed in the back of the cylinder block casting where the 3/8 UNC fasteners pass the tubular dowels.

Checking for this type of misalignment problem involved mounting the engine and gearbox together without a clutch assembly being installed. Once the engine and gearbox were bolted together, the gearbox top cover plate was removed for inspection purposes. At this point the crankshaft was turned with a ring spanner while the input shaft was observed through the top of the gearbox. In this particular case the input shaft did not rotate. This confirmed the input shaft was not binding on the spigot bearing and there was no misalignment problem.

Bell housings

The standard Lotus twin cam bell housing is 6.750” in length and is sourced from a Ford 105E Anglia. The bell housing is usually machined inside to provide the necessary clearance for the larger Borg and Beck clutch assembly. Ford part number for the bell housing is 105E-7505B

The bell housing installed in this vehicle has a front bell housing face to gearbox main casing distance of 6.4375” which is shorter than the standard Lotus twin cam bell housing.

After some research, it has been established the gearbox and bell housing was sourced from a Ford Cortina MK11 1600cc. Distinguishing features included a different casting number. Externally the bell housing differed from the 105E unit as the top external ribs do not run from back of engine block to top of gearbox main casing. The clutch locating lug for the slave cylinder is different and has a larger bore size. Subsequently the physical dimensions of the slave cylinder in much larger in external diameter and also longer than normal. The starter motor fixing location has three bolts instead of two, per the 105E bell housing.

The effect of installing a shorter bell housing changes the entire clutch setup and operation. The clutch installed height is incorrect and this could be seen by the push rod having to be adjusted beyond its normal operating point (outside its normal range).

Gearbox input shaft

The gearbox input shaft is non-standard and has been machined in an attempt to make it fit the gearbox.

However, it is too long and protrudes 2mm to 3mm beyond the front bell housing face. The standard twin cam gearbox input shaft is recessed by approximately 10mm behind the bell housing front face

The input shaft spline is also too short by approximately 15mm to 20mm and does not extend back inside the bearing carrier nose

The standard Lotus twin cam gearbox input shaft spline detail extends some distance inside the bearing carrier nose (tube)

The cumulative effect of the changes in all the above dimensions is, the clutch friction plate cannot move backwards away from the flywheel so it is no longer being driven (in other words it is unable to stall).

The Original flywheel

The original cast iron flywheel has in excess of 0.125" (3.10mm) machined off the front friction face. It is suggested that this amount of material being removed has nothing to do with refurbishment caused by a previous clutch failure. Typical amounts of material after a clutch has been allowed to run down to the rivets would be 0.015" to 0.020". To remove in excess of 0.125" from the friction face appears to be a deliberate attempt to move the clutch assembly forward in an attempt to increase the clutch friction plate to gearbox input shaft spline clearance.

Removing this large amount of material from the flywheel would also explain the excessive balancing marks/drill holes observed. The consequences of removing such a large amount of material from the friction surface change the entire clutch setup and operation. This has a flow on effect that influences the clutch lever position and push rod adjustment.

Flywheel friction face to cylinder block distance

As the engine had been rebuilt using an after market steel crankshaft and steel con-rods, it was essential to establish that both the crankshaft journal and fly wheel face were the correct distance from the back of the cylinder block. This distance is important as it determines the clutch installed height, release bearing and lever position. Measuring from the back of the cylinder block to the friction face of the flywheel provided the necessary information to be compared with a standard Lotus twin cam engine in another vehicle. This comparison confirmed that 0.125" of material had been machined of the original flywheel and in fact the back of the crankshaft was in the correct position.

Cylinder block face to clutch diaphragm fingers

A cumulation of measurements where made to determine the clutch installed height. This critical measurement from the back of the block to the diaphragm fingers was approximately 3 inches (76mm)

Original clutch driven plate

The original clutch driven plate was re-examined and was found to be modified

The rear spline locating boss had been machined in an attempt to provide gearbox input shaft clearance. Some 35% of the spline length had been removed. This reduces the spline contact surface area significantly and would accelerate wear between the clutch driven plate and input shaft.

It was also noted the friction material had worn trapezoidal in shape but the faces were parallel. Checking the cross-section of the friction material revealed there was a 0.010" to 0.015" taper across the surface. This only became apparent after examining the depth of the ventilation slots running across the friction material.

In other words the driven plate was dish shaped instead of being a flat disc.
This is best explained and comparing the two attached diagrams on pages 6 and 7
Note the very small air-gap created by the distorted friction material on the diagram
The driven plate has been distorted by the centre bottoming out on the splines and forcing it to take on a dish shaped appearance.

The crankshaft

The new steel flywheel was first checked with a micrometer to ensure the back and front faces had been machined parallel to each other. The flywheel was then checked for run-out and was found to be true. Measurements were then made between the flywheel and the back of the cylinder block at 9 O'clock, 12 O'clock and at 3 O'clock. This proved the crankshaft was perfectly square to the back of the block. If this was not the case, then the input shaft spigot would bind up in the crankshaft spigot needle bearing. It should be noted that spigot needle bearings do not tolerate any axial misalignment.

Solving the problem

There were a number of possible solutions to consider that might result in "a repair" However there were numerous constraints imposed in carrying this out in an effective manner. The constraints were as follows:

a) The engine and gearbox had been moved backwards approximately 4 inches (100mm)
b) The engine mounts and chassis were modified to suit the new position of the engine and gearbox
c) The foot-well extended/modified to suit the new owner
d) The bell housing has been modified to clear the extended/modified foot-well
e) The prop-shaft had been shortened to accommodate the new position of the gearbox

Installing a twin cam bell housing and clutch assembly was the first choice but was excluded because the engine mounts, chassis and prop-shaft had been modified. Being cognizant of costs, the logical and most cost efficient solution was to customise a clutch plate with an off-set splined centre. This means the centre should be off-set towards the flywheel whilst the centre spring-pack faced in the normal direction towards the gearbox. By modifying the clutch plate in this way, it should provide sufficient back clearance on the input shaft spline so the friction plate is free to "float" (and not be distorted)

New modified clutch plate

Looking at the original clutch plate, it was identified as a non standard after market component.
This plate was 215mm in diameter with an 8mm thick friction pad material riveted to the plate
A new replacement was sourced and was promptly modified to provide as much spline back clearance as possible. The following modifications were made

a) The wave-plate fingers had the rivets removed to allow the centre plate to be re-riveted on the other side closer to the flywheel so as to provide an increase of offset clearance of approximately 0.080" (2.0mm) which is the thickness of the centre plate.
b) The centre spline boss had the tapered counter-bore increased which provided an additional 0.080" (2.0mm) of off-set clearance
c) The centre plate and spring assembly was removed by drilling out the four large securing rivets.
   Four new stepped rivets were manufactured to the same dimensions as the original items.
   These rivets were tested by riveting them to the old plate before attempting to install them in the new clutch plate
   The riveting process was achieved by placing suitably mounted 0.500" diameter ball bearings either side of the rivet. The ends of the rivet were simultaneously peened over by using a 20 ton press that applied a force of 1500 psi. This produced a consistent mushroom head with a concave face.

Before final assembly and riveting process took place, the plate was temporarily assembled with some small screws and trial fitted to the gearbox input shaft to check the end-float/spline clearance.

Fortunately the bell housing had been previously modified with a large section of the casting having been removed around the starter motor pinion area. All that was required to gain access to the viewing port was to drill out six 1/8” pop-rivets which held an aluminium closing plate in position.

Once the closing plate had been removed, this gave an unprecedented view of the clutch friction plate, flywheel and gearbox input shaft. Despite flipping the splined centre over so the off-set is towards the crankshaft there is minimal spline exposed. However this modification finally produced 3mm to 4mm end-float which will only improve as the clutch friction material wears.
Note the fixing screws and nuts holding the centre spring plate together.

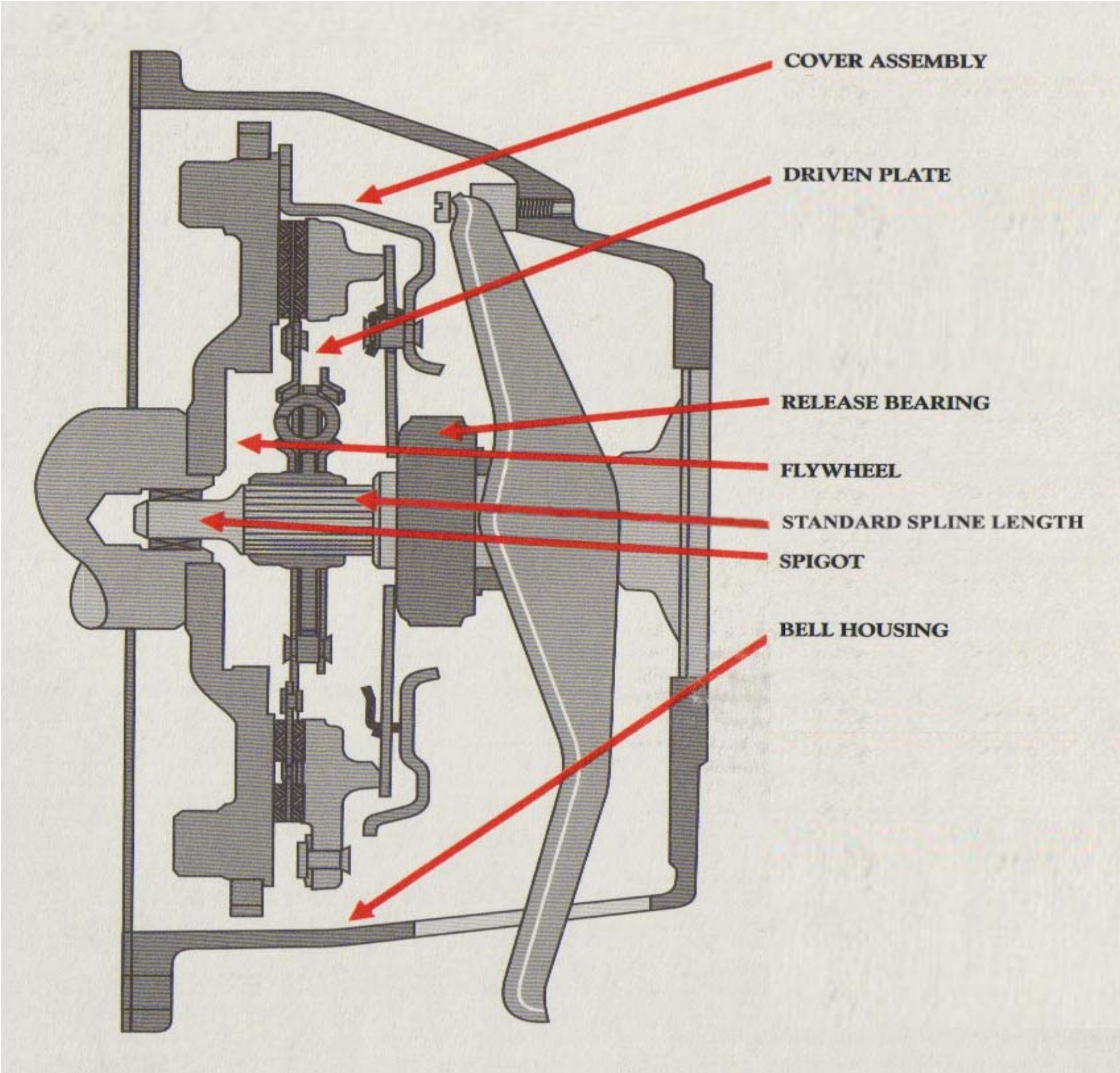
Clutch lever and pivot point
Once the new custom friction plate had been trial fitted and checked for clearance on the input shaft, the next item to check was the clutch lever operation. This was achieved by the engine and gearbox being fastened together, complete with the clutch assembly plus lever arm. By looking into the clutch lever opening it was possible to view the release bearing travelling over its full stroke. When the release bearing was moved backwards, the lever arm was observed to foul the leading edge of the bell housing opening. This was rectified by removing several shim washers under the pivot assembly. Adjusting the height of the pivot point allowed the lever arm to assume an optimum position. This had a flow on effect where the push-rod came within its normal operating position and the adjustment lock nut had thread either side of it. Previously, the clutch lever arm had been fully extended with the adjustment lock nut at the end of the push rod thread.

Conclusion
The gearbox, bell housing and clutch installation is a collection of unmatched components which have been modified in an attempt to get them to operate together. Given the unorthodox approach to this installation, it is not surprising the new clutch installation has not operated correctly. Now these problems are fully understood this confirms that they were pre-existing, prior to the engine and gearbox being rebuilt. These same problems were disguised by subtle machining and wear on critical components. With the clutch driven plate being distorted, it explains the problems associated with the engine and gearbox. In affect, the deformed clutch plate has applied axial pressure to both the crankshaft and gearbox input shaft. With constant pressure on the crankshaft (and centre main thrust washer), it would have caused oil starvation. With continuous contact and high rpm, this would explain why the crankshaft thrust washer failed catastrophically. The gearbox also shows signs of component problems with broken synchromesh teeth on the input shaft, badly worn input shaft bearing and a significantly worn thrust washer on the main gear cluster. The worn thrust washer explains the excessive end-float in the main gear cluster and why the gearbox would jump out of gear occasionally. It is unfortunate that this project has been compromised and constrained by the substandard modifications carried out by the previous owner(s). Whilst this problem has been resolved by various compromises, this is not a reflection of normal engineering standards practiced by The Elan Factory.

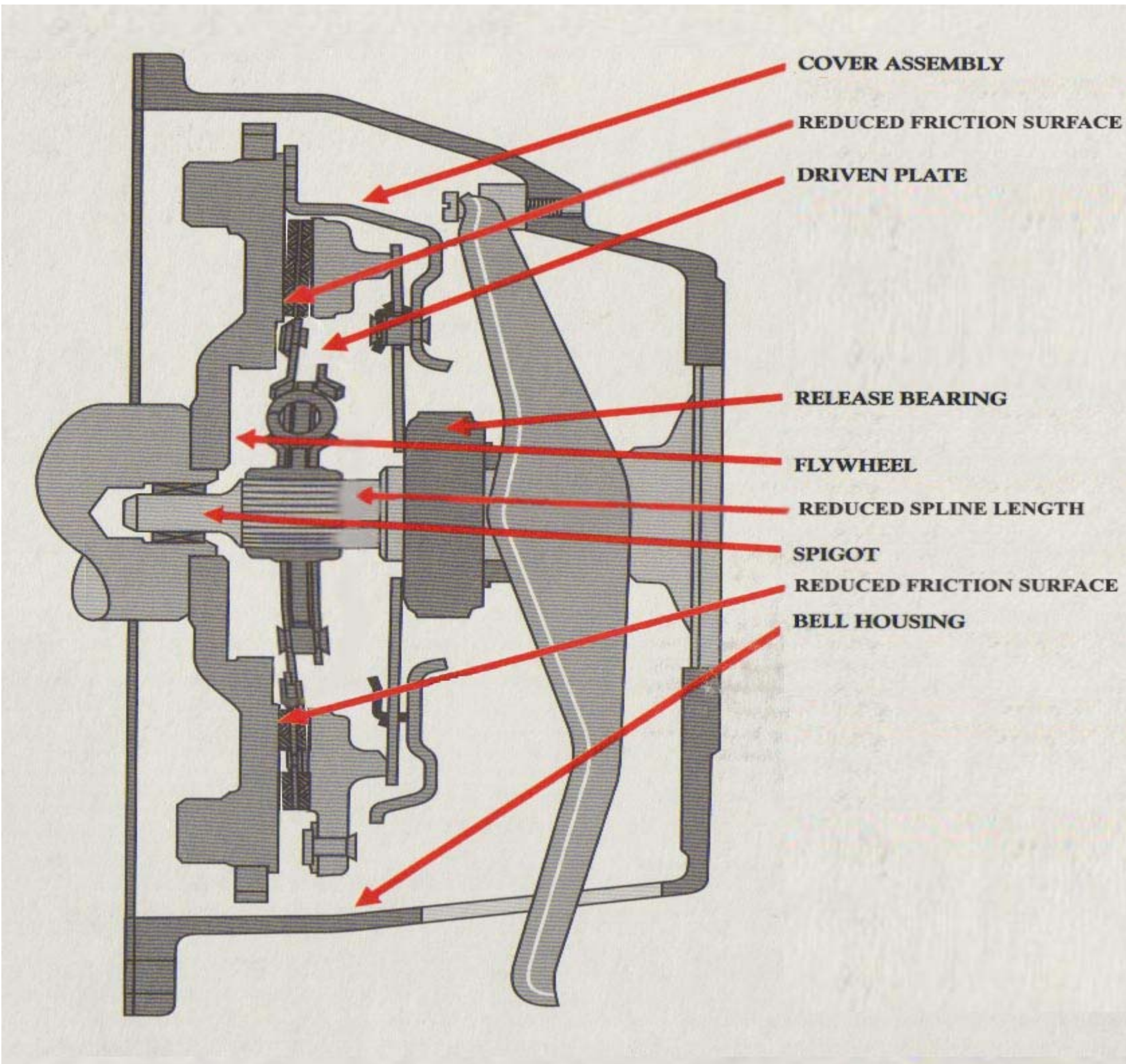
NOTE: The diagrams below are for illustration purposes and therefore are not identical to the Ford/Lotus twin cam bell housing and clutch assembly.

This diagram depicts a standard clutch assembly, flywheel and bell housing. There are several points of interest which are:

a) The input shaft spline and how it extends from the spigot to the release bearing carrier housing
b) The clutch driven plate position and appearance (not distorted)
c) The clutch friction material and how it is clamped between the flywheel and pressure plate
d) The spigot and how it locates inside the crankshaft

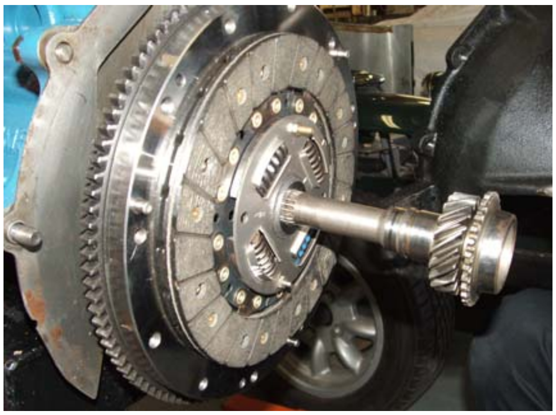


This diagram illustrates the clutch problem where the friction plate (driven plate) has no clearance on the gearbox input shaft splines. The friction plate is significantly distorted by being forced forward towards the end of the crank shaft. The driven plate assumes a dish-like appearance because of the reduced spline length on the input shaft. To prevent this from happening, there would normally be a reasonable amount of spline extending well into the release bearing carrier housing. If you look carefully you will note the friction material only contacts the flywheel on the inner edge by a very small amount. It should also be noted that the friction material only contacts the pressure plate on the outer edge by a very small amount. This explains why the friction material on the old driven plate has such a strange wear pattern.



Dismantled clutch plate and spring pack

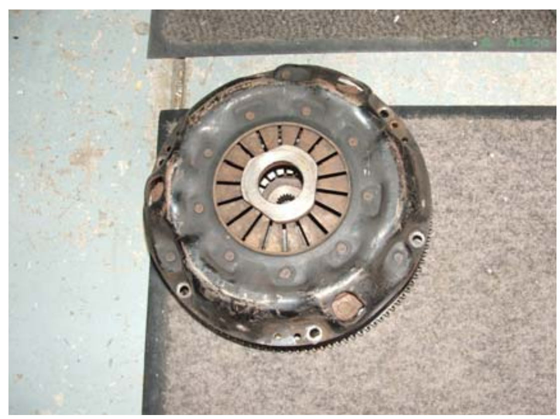
New stepped rivet for clutch plate



Dummy assembly of clutch plate

Clutch plate checked for run-out after riveting

Non standard clutch assembly installed



Standard twin cam clutch assembly

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