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REVIEW ON IMPROVEMENT SOLUTIONS IN MODERN RACE CLUTCH DESIGN

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ABSTRACT

To transmit the drive, in form of rotation, produced during the combustion process in the cylinders to the gearbox, where it is transformed into different ratios, a coupling element is needed. This is the task of the clutch. The clutch is the part that enables a gear change. A disconnection between constantly-spinning crankshaft and the gearbox must be realized to be able to stand still as well as to change gears.

Among many principles in design, the classical friction plate clutch has established it` position in vehicle design. Especially, race car rules predict the use of conventional multi plate clutches (in some cases single plate clutches are also used) which transmit engine torque into the gearbox via friction. A traditional multi plate clutch is composed of three basic elements: the flywheel, the pressure plate and the clutch plates (in race car practice, 4 plates are the limit). The flywheel is attached to the end of the main crankshaft and the clutch plates are attached to the gearbox input shaft using a spline. When a axial load is applied to the assembly, the friction produced between plates prevents any rotation between them and a solid drive is established without any additional mechanical engagement.

While a breakthrough was made with the new generation clutches in the 1980`s, made with Carbon as friction material, the current situation in this field of the transmission is saturated. All inventions lead to some improvements in the general design field, where the main improvement happens in the whole concept of the transmission (DSG or CVT).

Keywords: clutch, torque, friction plate, single plate, multi plate, rpm

1. INTRODUCTION

To establish a constant drive ("Power train") between the combustion engine, gearbox and the road wheels a disconnecting element is needed which allows the vehicle to stand still (while the engine is working) and to change gears (in the case of gearbox with fixed gear ratios used). The main disadvantage of the friction plate clutch is that they sooner or later reach there temperature limit according to which they are not more capable to transmit the full amount of torque without to slip. This means that the classical mechanic clutch, used via the drivers feeling, has to be much bigger in it`s final dimension.

A traditional race car multi plate clutch is consisted of a friction plate that transmits engine torque into the transmission itself. Layers of plates are alternately geared to the clutch housing, which is bolted to the engine flywheel and also to the clutch hub, which is attached to the gearbox input shaft. When a heavy axial, or clamp load is applied to the assembly, the friction produced between plates prevents any rotation between them and a solid drive without any additional mechanical engagement is established. Transmitting this drive depends on maintaining the clamp load. This is usually obtained by a series of diaphragm spring fingers which act as radial leaf springs and bear upon the rearmost plate in the assembly.

The combustion engine needs to achieve a minimum rpm value ($n_{T,min}$) to deliver the torque to the clutch and trough it to the gearbox. When the vehicle stands still, the gearbox input shaft is not spinning ($n_{G,1}$=0). The main clutch task is now to align these two rev numbers, without the minimum engine revs fall below the minimum rpm value ($n_{T,min}$) (Figure 1). This is not only achieved by the clutch itself. The driver (the electronic in case of a race car) regulates the engine load.

The clutch starts to slip during the coupling phase, which results in partial loss of energy into heat. The reverse process of disengagement is similar to the shown one. With electronic control these losses can be reduced to a minimum.

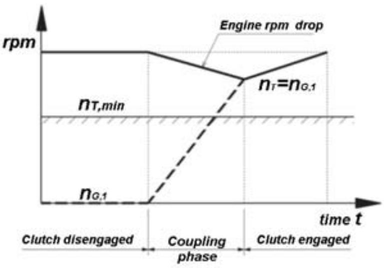

Figure 1. Idealized engaging process of a clutch

2. CURRENT DESIGN OPTIONS

According to the number of friction plates and type of heat dissipation the current design options are limited to two basic options: Single – plate (dry) and Multi – plate (wet) clutches where the carbon clutch is a improved develoment of one of clutches is considered to be carbon clutches (Figure 2). This is in fact a single or multi-plate clutch whereas the clutch and friction plate material is carbon fibre strengthened.

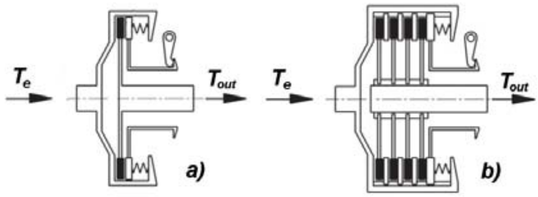

Figure 2. Switchable types of friction clutches a) Single-plate clutch b) Multi-plate clutch

Through continuous development, dimensions of today`s formula 1 clutches have been reduced, despite increasing torque transmitted from the engine. Formula 1 clutches transmitt over 600 Nm engine torque, nevertheless the clutch housing diameter fell from 175 mm (in 1990) to 111 mm (in 2002). The clutch housing is unifyed with the engine flywhell unlike to common clutch design where the flywheel and clutch housing are two separated parts. The clutch housing is made of titan whereas the friction plates and clutch disc is made from carbon fiber plastic strengthened material. By that. The clutch weight was reduced from 1800 g to 1060 g (including the flywheel). As far as friction coefficient is concerned, carbon fiber strengthened material solutions were a breakthrough. One of the limitations of traditional metal materials was that the friction coeficient fell as temperature increased. With the introduction of carbon fiber as friction material in the 1980's this problem was eliminated and so the friction coefficient was effectively raised in operational use. With this type of material combination, the clutch can endure temperatures to about 1000°C without fall in friction coefficient. The lifespan of such clutches is estimated to about 2000 km. A 3D explode view of such an clutch is given at Figure 3.

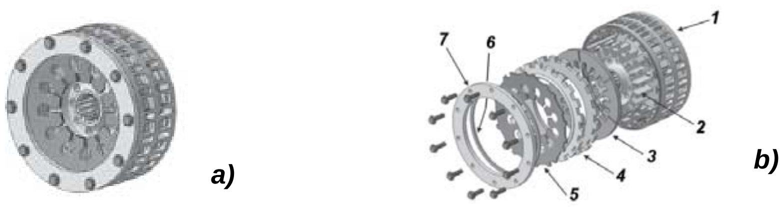

Figure 3. 3D explode view of an Formula 1 clutch a) assembly b) explode view
1)Clutch housing; 2)Hub; 3)Intermediate plate; 4)Clutch disc; 5)Diaphragm spring;6)Pressure ring; 7)Cover

3. SOLUTIONS IN DESIGN IMPROVEMENT

One the main design properties for every clutch, regardless of the application it is used in, is the clutch diameter. According to basic mechanics, frictional force created between the clutch plates will be equal to the Normal, or pressure force within the assembly (F_{pr}) multiplied by the friction coefficient (μ) of the plate materials. All this happens between two plates so it has to be multiplied by the amount of plates in the clutch (4 plates are the limit in F1 praxis). Created friction can be visualized as a series of forces that can act tangentially from the inner diameter of the plates to the outer. The Torque then carried will be equal to the sum of these radial forces multiplied by the distance of each one from the input shaft axis. Finally, expression (1) can be obtained.

$$T = k_{dyn} \cdot T_{Th} = k_{dyn} \cdot F_{pr} \cdot \mu \cdot j \cdot r_{cl} \quad \ldots \quad (1)$$

- T – Incoming clutch torque to transmit
- k_{dyn} – Dynamic Increasing factor
- T_{Th} – Engine torque
- F_{pr} – Pressure force that has to be affect the pressure plates
- μ – Friction coefficient according to the pressure and clutch plate material
- j – Number of pressure plates
- r_{cl} – Clutch radius

The last two decades in race clutch design improvement has been marked by reducing the clutch diameter in order to lower engine`s centre of gravity and so the transmission system. At the same time, as already mentioned, the inertia of the clutch assembly was itself reduced (via the use of sophisticated carbon fiber materials) which in turn speed up gear changes and enhance engine response. This improvement leaves to a reduction in the diameter and working area of the clutch. That in turn means that the clutch radius from expression (1) decreases. The number of pressure plates is reduced to 4 because of practical reasons. In order to transmit the same amount of torque to the gearbox either μ or F_{pr} must rise. The dynamic Increasing factor (k_{dyn}) cannot be taken into consideration in the above mentioned discussion because of its heavily predictable dynamic nature (authors adopted a dynamic Increasing factor of 2 throughout this overview). If the pressure force has to be raised so much to transmit the given amount of torque (in F1 over 600 Nm) it means that a huge amount of pressure force has to be performed for such amount of torque transfer. This withdraws sophisticated hydraulic systems that can accomplish such given task which are not taken into consideration in this paper. According to the above mentioned expression, authors established a simple mathematical model to predict the clutch diameter for a given case of torque to transmit. The only parameter that was observed as a variable was the friction coefficient and through it the material. Based on friction coefficient values given in table 1, authors could accomplish a relationship between engine torque and clutch diameter as shown on Figure 4.

Table 1. Frictional Coefficients for some Common Material Combinations used in (the assumption is that the surfaces are lubricated and Greasy)

Material Combinations (clutch disc – friction plate)			Friction coefficient in individual cases (μ)			
			Single plate (j=1)	Pressure force F (N/mm^2)	Multi plate (j=4)	Pressure force F (N/mm^2)
Solution 1	Carbon (hard)	Carbon	0.12 - 0.14	20	0.48 - 0.56	5
Solution 2	Carbon	Steel	0.11 - 0.14		0.44 - 0.56	
Solution 3	Chromium	Chromium	0.34		1,36	

Three different material combination solutions could be separated (shown in table 1). Theoretical results trough equation (1) are shown on Figure 4. As an example, a engine torque of 600 Nm was considered. For every, of the three given solutions, three different clutch diameters come into question. The smallest one (S1,S2=90 mm, S3=50 mm) saves space, weight and has a small moment of inertia. The clutch price also remain small. The larger clutch (S1,S2=110 mm, S3=60 mm) offers other benefits. The fading stability enhances so as the clutch lifespan. The activation force decreases in which the pressure force is reduced for the same amount of torque. A smaller clutch diameter allows a lower engine mounting in the vehicle which results in a better handling of the car which is the case in high speed applications such as Formula 1.

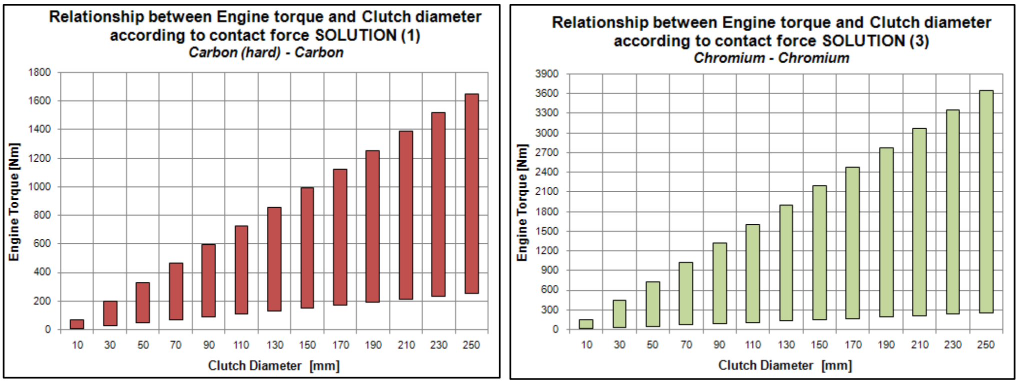

Figure 4. Relationship between Engine torque and Clutch diameter according to contact force. Solution (1) and (2) result with basically the same numerical values due temperature was not taken into account. That's why Solution (1) has greater practical significance.

Figure 4 shows just two of three solution results, because solution (1) and (2) give the same results. This is explained by the fact that the given model (equation (1)) does not include any temperature activity and it`s influence at the final torque. Because of that, solution (1) which uses Carbon-Steel combination as friction material, has a greater practical importance than solution (2) with Carbon – steel combination. Theoretically (looking trough this model), solution (3) would be ideal. The clutch diameter for this material combination is almost half that of solution (1). However, solution (3) is yet not far enough explored to be ready for practical use in racing (structural strength a temperature resistance are not met).

4. DISCUSSION AND CONCLUSION

The racing technology field offers many different friction covers. Covers with high wear widths are used when many starts are driven and when a long life span is required. This is the case in Rally, Rallycross, autocross, touring and long distance races. Very light clutch discs are used for Circuit racing cars. They are characterized by a low inertia and a small clutch diameter. Carbon clutch disc technology enables extreme small clutch diameters with high temperature resistance.

Authors attempt was to establish a simple and practical model which could overview the main topics in race clutch design, starting with clutch diameter and rounding it off with temperature influence. The core of this model was based on the number of plates with some friction coeficient and the their radius. Practical limitations come afterwards when a hydraulic system has to be used to release required forces to transmit the torque.

As far as friction coefficient is concerned, one of the limitations of traditional materials was that this fell as temperature increased. With the introduction of Carbon as the friction material in the 1980's this was eliminated and so the coefficient in service effectively raised.

Alternatively more plates can be added. A typical 140mm dia twin plate race clutch might be capable of transmitting 750Nm, whereas a triple plate increase this to 1100 Nm. In practice 4 plates are the limit. The efficiency of the clamp system is another area that can help increase effective capacity and this has led to the development of the 'pull clutch', which we will look at next month

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