Testing Apparatus and Test Cycle for Centrifugal Clutches: A Review

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Abstract : Clutch works as flexible link between a driver shaft and driven shaft. In automotive application, clutch mainly connects engine crankshaft to the input shaft of the gearbox. Engagement and disengagement of automotive clutch takes place either manually or automatically. Centrifugal clutches fall under the category of friction clutches which make use of centrifugal force for engagement. From the beginning, automobile centrifugal clutches have gained attention of researchers mainly due to challenging operating characteristics. Even though rigorously designed, automotive centrifugal clutch works under totally different conditions then predicted. Many researches have been carried out to improve characteristics, efficiency and lifespan of automobile centrifugal clutches. These researches mainly include areas like design optimization, dynamic properties, slippage parameters, drag characteristics, heat generation, heat transfer models, judder, friction material properties, load - torque capacity and usable clutch life. In this paper, researches allied to testing of centrifugal clutches have been reviewed and their results are consolidated and discussed.

Index Terms **- Friction clutches, Centrifugal Clutches, Clutch Testing, Testing Apparatus.**

I. INTRODUCTION

Clutch is one of the most important components of automobile driveline that has undergone significant changes during past decades. In transmission layout of a vehicle, clutch is a releasable coupling which connects the crankshaft with input shaft of the gearbox. It is said to be engaged or in, when the shafts are coupled, and disengaged or out, when they are released. Clutches mainly work on a principle of friction where they fall into two main categories of positive engagement and progressive engagement. The positively engaged clutches are connected with some mechanical devices such as splines, keys, dogs, jaws or teeth. It is when engaged, both the shafts rotate together and when positively disengaged, no torque can be transmitted from the driving to the driven shaft. In contrast, the progressive type clutch is gradually engaged, so that the speed of the driving shaft falls for a while, simultaneously, that of the driven shaft rises from its initial stationary state until both rotate at equal speeds. Further, clutches are also been classified as wet clutches and dry clutches. The wet clutches are required to be operated with sufficient amount of lubricating oil whereas dry clutches work without lubricating oil throughout their application [1].

Centrifugal clutch is a special kind in which engagement occurs due to centrifugal force while disengagement happens through spring force. Figure 1 shows a schematic of centrifugal clutch generally used for automotive drive train. In the centrifugal type clutch, the centrifugal force is used to generate the required force for keeping the clutch in engaged position. Moreover, elimination of friction plate, clutch plate and pressure plate makes the clutch assembly simple. The advantage of the centrifugal clutch is that no clutch lever is required. The clutch is operated automatically depending upon the speed of the engine. Moreover, when used with CVT (Continuous Variable Transmission), centrifugal clutch allows driver to simply twist the accelerator for driving. The CVT transmission pulley is driven by the crankshaft through belt drive. This driven pulley is connected with the driving plate of the clutch. The transmission pulley and the driving plate are mounted on the output shaft of the clutch and can rotate freely with the help of bearing. This output shaft provides power to the final drive. The driving plate contains three pivot points for clutch masses. Clutch masses are pivoted on single point on the driving plate and interconnected with the help of clutch springs. The clutch springs are tension springs which are used to retain position of the clutch masses. Clutch masses are lined with friction material on the outer periphery. The entire assembly is covered by the clutch housing which is bolted to the output shaft. Therefore, output shaft start rotating as soon as the clutch housing rotates. The centrifugal force on clutch mass increases with engine speed and overcomes the tension force of spring at designed value of RPM. As the engine speed reaches to designed value, the clutch masses glide outward due to increased centrifugal forces. The friction linings on the clutch masses are then rubbed on the inner face of clutch housing. Gradually friction increases between lining and the clutch housing and the clutch is engaged with final drive. The centrifugal force increases rapidly up to predefined speed value after which no great increase takes place. The clutch remains in fully engaged position unless the engine speed is decreased. At idle speed of engine, clutch remains in disengaged position because the spring tension remains higher than the centrifugal force produced due to less speed. Proper ventilation on the clutch housing keeps the clutch at moderate temperature. Dry running of centrifugal clutch can damage the linings as well as the clutch housing [1], [2].

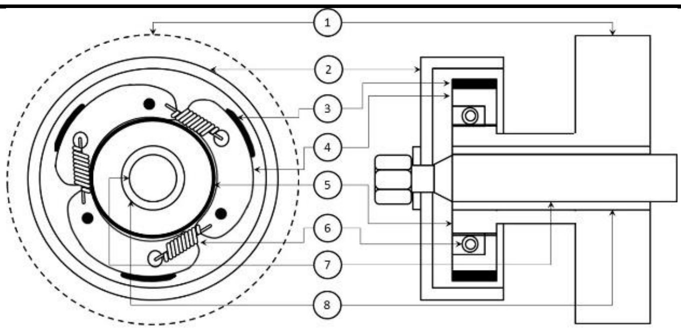


Figure 1 Centrifugal Clutch

Centrifugal clutches have advantage of low production cost and are easy to modify with simple changes in design to suit particular application. Centrifugal clutches have very low maintenance cost than conventional dry plate clutches. Due to its built-in slip characteristics at low engine speeds, centrifugal clutch is more open to abuse. This results in overheating of the clutch liners and causes rapid wear. Moreover, the relationship of engine speed and clutch load is fixed in case of centrifugal clutch and when judder occurs it becomes a major problem, which involves component replacements as remedy [3].

II. Literature Review

P B U ACHI [4]: The design and testing of automotive centrifugal clutch was presented. The clutch was tested with two different engines. The absorption type dynamometer was used to generate the load on clutch. The equation to derive the torque capacity of clutch was also presented. The clutch performance test was carried out up to 2500 RPM. He also suggested including appropriate cooling system to avoid overheating of centrifugal clutch.

Nathan B. Crane et al. [5]: The compliant mechanism design techniques was used to analyze compliant centrifugal clutches and to develop effective new centrifugal clutch concepts. The pseudorigid- body model, rigid-body replacement synthesis, force-deflection analysis, compliance potential evaluation, and compliant concept evaluation were employed in this work. The clutch designs were prototyped and tested to measure their torque-speed relationships. The setup used for testing of centrifugal clutches was on lathe machine. The tachometer was used to measure the clutch speed. The clutch was rotated inside the stationary clutch drum. The output torque was measured by the reaction torque gauge mounted between the tailstock of the lathe and the clutch drum. The clutch drum was mounted on the driving shaft with bearings. Each clutch was cycled through the speed range of the lathe two to three times.

Ryan G. Weight et al. [6]: Design and testing of high-torque-capacity floating opposing arm clutches was presented. Two Multi-layered Floating Opposite Arm clutches were fabricated and tested for torque-speed characteristics. The test setup layout consisted of an engine as main power source with a large torque output. The engine output was attached to a jack shaft in order to provide the necessary input. The jack shaft had the clutch assembly on one end. Output of the clutch was given to the final shaft with a water dynamometer break to load the clutch and measures the transferred torque with a torque transducer. There was one tachometer on the jack shaft and one on the output shaft to measure the speed. There were two types of tests performed in order to obtain the necessary evaluation data. The first test was the RPM Contact Test Procedure. The objective of this test was to judge the accuracy and smoothness of contact. The second test was the Torque Test Procedure, which applied an increasing load to the output shaft in order to determine maximum torque capacity.

Tetsuya Kimura [7]: Study on dry centrifugal clutch judder was presented. The judder phenomenon was numerically simulated and experimentally analyzed. Vibration measurements on scooter were performed for 50 seconds using a two clutches (a) a worn-out clutch (b) a brand new clutch. The worn-out clutch showed greater vibrations on the handlebar of vehicle. Centrifugal clutch test equipment was used to measure the clutch transfer torque characteristics. The test equipment consisted of electric motor, centrifugal clutch assembly, torque sensor, brake and flywheel. The flywheel was used to replicate the inertia of vehicle which was set an equivalent value for the total weight of the vehicle.

Chyuan-Yaw Tseng et al. [8]: A dynamic simulation model for scooters with a mechanical-type CVT was developed. The maximum torque transmitted by the clutch (Tc) depends on the rotational speed of the CVT output axis. Based on experimental data, an empirical equation was obtained as:

$$T_C = 0.000011554\,\omega_C^2 - 0.0134\,\omega_C - 0.5$$

N. Karthikeyan et al. [9]: The study of different design possibilities for increasing the air flow through CVT housing for reducing the clutch temperature was presented. An experimental validation is done with a defined driving cycle to validate the simulation results. Experiments validation was carried out at ambient temperature of 30 °C. Temperature stickers were used to measure the clutch surface temperature. Measurement was done according to a driving cycle generated using city driving pattern. There was more clutch slippage at lower vehicle speed or engine speed causing higher generation of heat. The maximum speed of the vehicle was 48 KMPH in this City driving cycle and duration was 1900 seconds. Frequent acceleration and deceleration at regular intervals was used for slippage to occur.

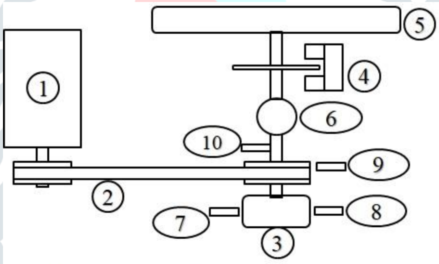
Tse-Chang Li et al. [10]: Investigation on the performance of 18 kinds of friction liners with different material composition was presented. The relationships between ratio of static torque to dynamic torque and ratio of friction coefficient to relative velocity were established for all friction liners of centrifugal clutch. All specimens were tested for 100 clutch cycles using CVT dynamometer.

Tse-Chang Li et al. [11]: Investigation on the judder characteristics of 18 kinds of friction liners with different material composition was presented. All specimens were tested for 100 clutch cycles using CVT dynamometer. The clutch was accelerated from idle speed to drive speed of 500 RPM. The sliding velocity between friction liners and clutch drum was taken as decisive factor for complete engagement i.e. zero sliding velocity represented as complete engagement. Thus, one cycle was defined as rotation of clutch from complete disengagement to complete engagement. The judder test for each friction liner specimen was performed with 100 cycles.

Chih-Hsing Liu and Yen-Pin [12]: A numerical model to analyze the dynamics of centrifugal clutches, which can estimate the rotational speed of initial contact, output torque, contact width, and contact pressure profile for friction lining during the clutch operation was presented and validated through experiments. The experimental setup used for the torque test on commercial centrifugal clutch. The drum was fixed during the test. The rotational speed of clutch increased from 0 to 2000 rpm, and then decreased until stop. The output torque obtained from both numerical and experimental results were compared which shows deviation of 1.9%.

III. DISCUSSION

The literature review indicates infrequent availability of dominant test apparatus and test cycle for centrifugal clutch used on vehicles. Rigorous testing at design level helps to predict the particular characteristics of any component. Researches related to centrifugal clutch show well developed theoretical models for design. However, the test apparatus and test cycle have not gained enough attention yet. The results show drastic drop in friction characteristics of clutch liner. The gradient of the curve of friction coefficient (μ) to sliding velocity (v) drops down to negative [7], [11]. The deteriorated condition of clutch friction liners encourages unwanted judder. The most fundamental way to solve the clutch judder is to improve the friction characteristics of the clutch, thereby preventing the μ-v curve from obtaining a negative gradient. Since the friction characteristics of the clutch are controlled by acquired factors such as the riding habits and the environment, it is difficult to predict ideal friction characteristics under all conditions. However, CVT dynamometer appears to be promising to test the centrifugal clutch, conferring to literature review, a general layout of centrifugal clutch testing apparatus is shown in figure 2. The electric motor with sufficient capacity can be used to replace the engine. The motor provides the drive to the centrifugal clutch either through CVT or belt-pulley arrangement. The output shaft of the clutch contains load wheel/ flywheel to replicate the road load of vehicle. The brake is also used to retard or stop the inertia of load wheel as and when required. The torque sensor measures the transmitted torque by the centrifugal clutch during different loading conditions. One or more temperature sensor can be used to note the clutch housing temperature, temperature around clutch assembly and ambient air temperature. Tow RPM sensors gives the reading of clutch housing RPM and driven pulley RPM. Sliding velocity of clutch friction liner can be derived using these two speeds. Vibration sensors or acceleration sensors help to study the judder characteristics of centrifugal clutch at different stages of application. Using proper test cycle, different characteristics of centrifugal clutch can be investigated and relations between parameters can be derived using this test apparatus. The derived relations and equations can be utilized further to predict the change in friction characteristics of centrifugal clutch more precisely.



1. Electric motor
2. Belt drive
3. Centrifugal clutch
4. Brake
5. Flywheel/ Load wheel
6. Torque sensor
7. Temperature sensor
8. Clutch housing RPM sensor
9. CVT pulley RPM sensor
10. Vibration sensor

Figure 2 Layout of Centrifugal Clutch Testing Apparatus

The test cycle which has been used to test the clutch also plays vital role. Previous section shows consolidated data available for different test cycle available. However, the test cycle should imitate different driving conditions and terrain conditions just like a vehicle experiences during dynamic condition.

IV. CONCLUSION

Different types of testing apparatus and test cycles exist today which may be classified in accordance to their layout, type of test employed and level of functionality achieved. This paper reviews the testing methods and testing equipment used for centrifugal clutches which have engine providing main motive power. The paper shows the history of testing procedures based on application of centrifugal clutch and reviews the various concepts in this field. The interest in centrifugal clutches has been there since many decades and various researchers have presented different designs. With the increasing demand of CVT driven scooters with centrifugal clutch, it can be said that the development of testing methods and apparatus for centrifugal clutches has to reach a point where the different driving conditions of vehicle can be simulated and tested on the test apparatus.

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