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Determining the Static and Dynamic Coefficient of Friction and Its Causes for Variation

Saul Herscovici
John Deere Waterloo Tractor Works

THE PERFORMANCE OF friction materials may differ from one application to another even when identical parts are used due to changes in vehicle mass, spring rate, energy transfer, etc.

It is necessary to know the material static and dynamic coefficients of friction and their variations in order to protect the power train from failure. If the static coefficient of friction is too high in comparison to the dynamic coefficient, the overload torque peak required to breakaway the clutch may be too high to protect the transmission components from failure by allowing a momentary slippage. If the static coefficient of friction is too low in relation to the dynamic coefficient of friction, frequent clutch slippage may occur, leading to excessive heat generation and possibly resulting in thermal failure.

For these reasons a friction material selected for a particular application such as a clutch or brake is often tested in the prototype unit to determine its operating characteristics. The prototype may be a simple test fixture, or a complete unit to simulate actual field conditions. This can lead to a large number of testing units, each one having some variation from the others. It also makes it impossible to maintain a fixed set of operating conditions that would be uniform between the different testing units in order to establish a correlation between the friction performance characteristics.

A typical test fixture used to determine the friction coefficients will be discussed first, and it will be followed by a special friction test fixture that, if widely used, can lead to the establishment of a common language between the friction material suppliers and users, as well as lead to improved design performance.

PARTIAL VEHICLE TEST FIXTURE

Fig. 1 shows a typical application of a clutch in a test fixture that consists of an engine, a transmission, and a dynamometer. The clutch torque is determined by the following equation:

$$T = \mu P A R_m N \tag{1}$$

$$\text{where } R_m = \frac{2}{3}\,\frac{R_o^3 - R_i^3}{R_o^2 - R_i^2}$$

where:

T = Torque
μ = Coefficient of friction
P = Surface pressure
A = Friction surface area

ABSTRACT

A simple and economical testing fixture and method that may be used for determining the static and dynamic coefficients of friction and the operating conditions that cause their variation is described in this paper. Its advantages are compared to those of a partial vehicle test fixture. This testing method could provide a basic set of data that can be properly converted by the designer to predict the response of a clutch or brake in a new application.

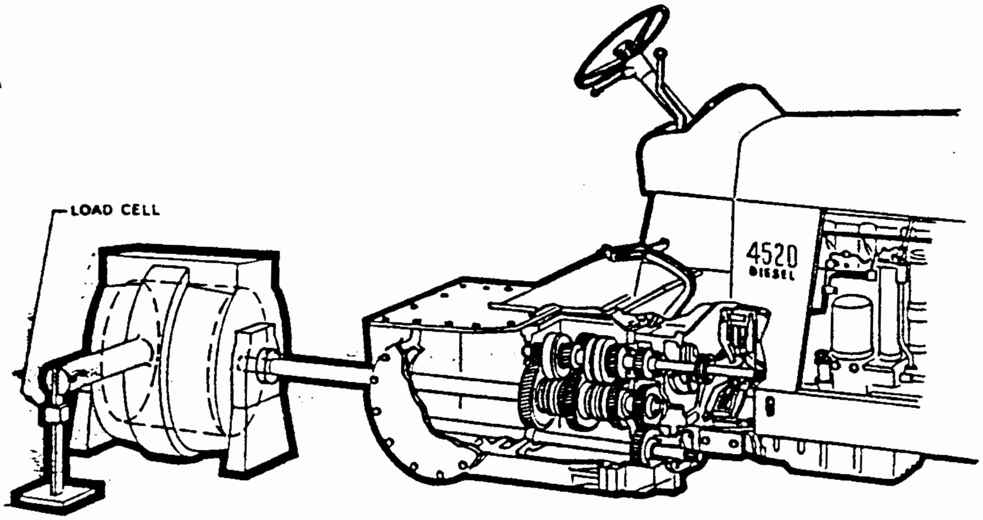


Fig. 1 - Tractor adapted to dynamometer test

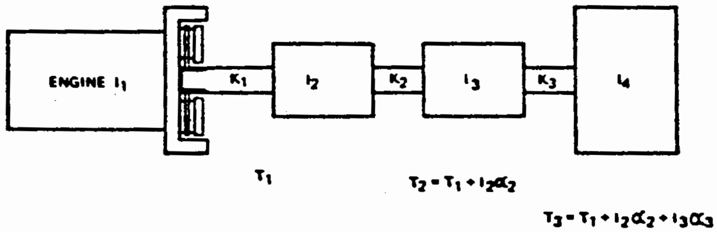


Fig. 2 - Schematic representation of tractor test fixture

N = Number of friction surfaces
R_m = Clutch mean radius
R_o = Friction surface outside radius
R_i = Friction surface inside radius
K = Spring rate
I = Angular moment of inertia
α = Angular acceleration

The coefficient of friction in the above equation is the only quantity that cannot be directly measured. It is determined from tests where the torque is measured by a known pressure in a clutch of a fixed area and mean radius. The above equation may be rewritten as follows:

$$\mu = \frac{T}{PAR_m N} \qquad (2)$$

Tests show that the coefficient of friction is affected by the operating conditions, and can also vary for no obvious reason in an ideal application where the operating parameters remain constant. To make matters worse, the static and dynamic coefficient of friction vary independently (1)*, the static coefficient generally being higher than the dynamic coefficient.

*Numbers in parentheses designate References at end of paper.

Torque and pressure measurements can be taken to determine the coefficients of friction of a material by use of a strain gage torque meter and a set of slip rings. The location of the torque measuring device is critical as it will also sense an inertia torque (2-4) caused by the acceleration of parts in addition to the torque generated by the engine.

Fig. 2 is a schematic representation of the test fixture shown in Fig. 1. It shows that there are three possible locations for torque meters on the three shafts. In addition to that, a load cell may be used to determine the dynamometer force at a known arm length as shown in Fig. 1. Each location will show a different amount of inertia torque because the number of parts between the clutch and any one of the four locations varies. A torque meter located on the shaft marked "K_1", to measure friction torque, will show the least amount of inertia torque because it is located closest to the friction surfaces. The highest variation in friction torque due to inertia occurs during clutch lock-up or breakaway as the acceleration is highest at that time. This torque is often attributed entirely to the static coefficient of friction as no accelerometers or other means are used to determine the level of inertia torque.

SPECIAL PURPOSE TEST FIXTURE

A special purpose test fixture can provide a simple and economical testing method, and can eliminate most of the

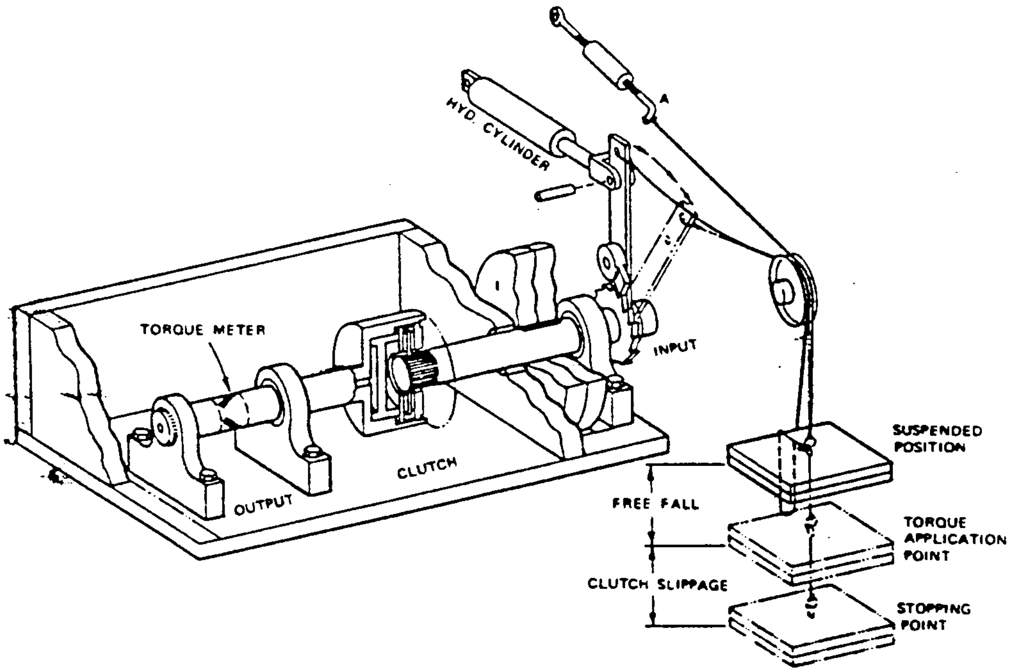


Fig. 3 - Special test fixture

difficulties encountered in determining the static and dynamic coefficient of friction that occur in a conventional test fixture. In addition to that, the special purpose test fixture shown in Fig. 3 enables determination of the changes in the coefficient of friction in relation to changes in the operating variables.

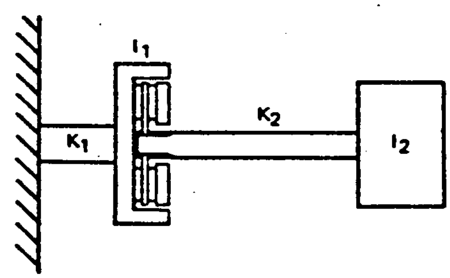
The test fixture is composed of a clutch with a stationary output shaft, a rotating input shaft with ratchet wheel attached, a torque meter on the output shaft, an arm with a ratchet pawl, a hydraulic cylinder, and a set of weights that can be dropped through a variable distance.

Sliding at the friction surface at a slow rate of load application is produced by extending the hydraulic cylinder. Impact loading may be applied by disconnecting the wire rope from hook "A" with the weights at a known height above the point of torque application. The velocity at impact may be changed by varying the free fall height of the weights with the cylinder pin removed.

The main advantages of this fixture are that the tests can be conducted at a low level of energy dissipation, and the absence of torque required to overcome inertia of parts between the friction torque and the torque meter. A dry clutch composed of a single disc and two plates 0.090 in. thick with a friction area of 14 $in.^2$, a mean radius of 2.25 in., and a pressure of 100 psi when rotating 18 deg. will raise the average temperatures of the plates by 1.2 F at a friction coefficient of 0.30. When a wet clutch is used, a sufficient amount of oil may be circulated to maintain the temperature constant.

Fig. 4 is a schematic representation of the special purpose test fixture.

The following are some of the parameters that may be varied individually or in groups over the operating range in order to evaluate their effect upon the friction coefficient and clutch performance:



IF $K_1 \gg K_2$ AND $I_1 \ll I_2$ THEN $K \approx K_2$ AND $I \approx I_2$

Fig. 4 - Schematic representation of special purpose test fixture

TEMPERATURE - Effect of material resilience, brittleness, and oxidation temperature levels may be determined.

SURFACE FINISH - Determines the microscopic total contact area-pressure (5).

FRICTION MATERIAL STRUCTURE - A highly porous and resilient material can provide a high amount of internal damping and oil circulation.

OIL VISCOSITY - Determines resistance to shear affecting the amount of viscous damping in wet applications.

OIL ADDITIVES - These are widely used for antichatter characteristics.

INERTIA OF PARTS - This affects the response to vibrations.

PRESSURE - May affect the microscopic contact area, internal damping, and oil film thickness.

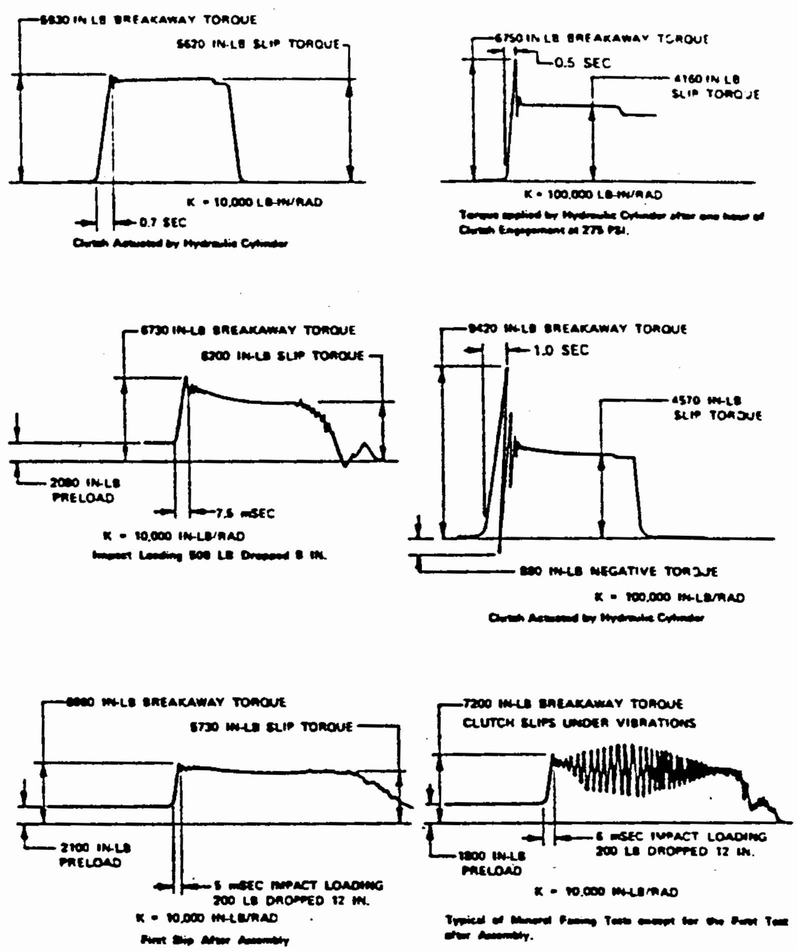


Fig. 5 - Typical torque curves made in special test fixture

RATE OF TORQUE APPLICATION - Response to rate of loading or impacting varies.

GROOVE PATTERN - Removal of oil at the contact surface by wiping action reduces the oil film thickness and increases the friction coefficient.

SPRING RATE - This affects the system response to vibrations.

ENGAGEMENT TIME TO BREAKAWAY - Microscopic area of contact may increase with time to result in a higher coefficient of friction on some materials.

RELATIVE VELOCITY - The coefficient of friction varies somewhat as the velocity at the friction surface varies. Often it increases sharply when the relative velocity approaches zero.

The following advantages may be derived from the ability of controlling the variables:

1. Test results may be universal. The testing conditions can be well defined and maintained within the desired boundaries. Factors may be determined for different types of oil.

2. Clutch or brake performance may be predicted for extreme limits of operating conditions.

3. Wear and heat generation is maintained at an insignificant level. The operating temperature may be closely maintained at any desired level by use of heated or cooled oil in wet applications, and by use of electric coils on one side of the separator plates on dry as well as wet applications.

4. Friction materials may be returned from a wear test after they have been subjected to a certain number of cycles or hours of test for comparison with new material operating characteristics.

5. The change in the friction coefficient due to change in the relative velocity may be determined at known surface operating conditions. The relative velocity on the test fixture may be provided by operating the hydraulic cylinder with a constant flow pump. Changing the amount of flow at different constant levels will change the relative velocity. An average relative velocity at impact loading may be obtained by recording the angular displacement versus time.

There are some significant disadvantages that are worth discussing. One variable that cannot be measured is the higher relative velocity (5).

The effect of the centrifugal force on the coefficient of friction cannot be evaluated. While it may have no effect on dry applications, it will certainly create a radial flow in wet applications. The level of the centrifugal force is low in comparison to the other forces present during op-

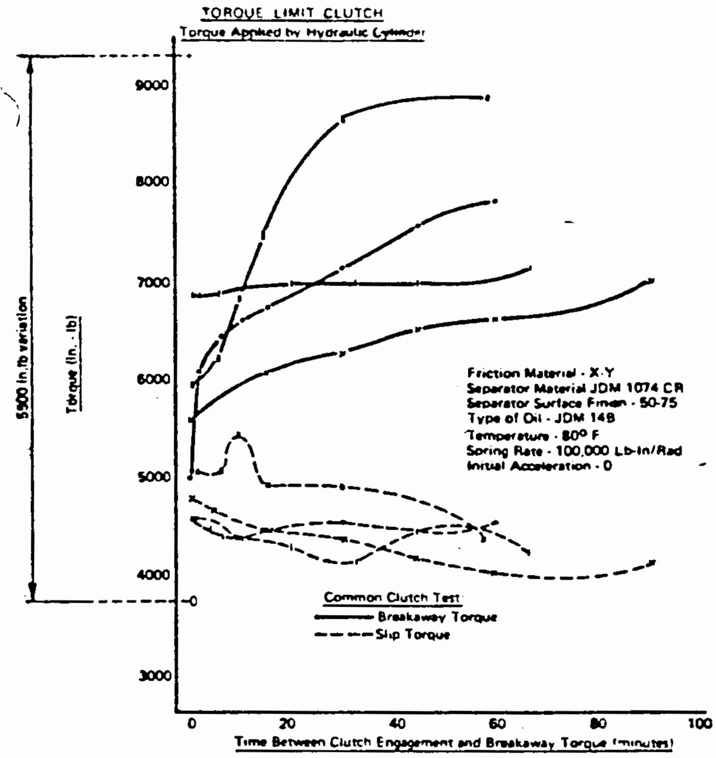


Fig. 6 - Static and dynamic coefficients of friction variation with change in engagement time

eration; therefore, its effect in a clutch or brake with good oil distribution is expected to be insignificant.

Fig. 5 shows several individual tests conducted under conditions described in Fig. 6 except for the change in spring rate as noted. Fig. 6 shows a series of tests where the only variable was the time between clutch engagement and breakaway torque.

CONCLUSIONS

Although transmission test fixtures as shown in Fig. 1 vary from one setup to another, in principle they are similar as they can be expressed in a series of shafts and masses as shown on Fig. 2. The schematic representation of the special purpose test fixture is shown on Fig. 4. It can be expressed by a single mass-spring rate. This makes the analyses simpler and the test data more representative.

Some of the operating characteristics that have a significant influence on the friction coefficient, such as the temperature, surface finish, and surface contamination, are continuously changing in any test fixture that has many cycles of slip.

This test appears to be most suitable for breakaway tests, but the test results can be applied equally well for lock-up conditions since any particular vehicle will have the same physical geometry, mass, and spring rate whether it is subjected to a lock-up or a breakaway. The other factors that may be different such as acceleration, temperature, and velocity over a limited range, can be varied on the test fixture to suit the application.

A further comparison between the transmission unit and the special test fixture shows that the latter offers the ability of closely controlling the testing conditions as well as a high degree of repeatability. It is hoped that this testing method would provide a common base for measurements of friction materials operating characteristics. Once this method becomes widely used, charts with more detailed and meaningful friction materials operating characteristics will become available to enable the designer to predict confidently the operating modes of a clutch or brake.

This type of basic friction data will become useful with the increasing trend of vehicle dynamics study by computer.

ACKNOWLEDGMENT

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