

Vibrational Behaviour of Clutch under the Influence of Coefficient of Friction– A Review

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ABSTRACT: The clutches in an automatic transmission transfer torque from the engine to the gearbox. During engagement of clutches when vehicle is started or during engagement of clutch when vehicle is in motion, the friction clutch generates chatter or also called as Judder vibrations. It is necessary to analyze the effect of frictional lining material characteristics on propensity to judder. This paper presents a study on an investigation of the driveline torsional vibration behaviour, judder, which takes place during the clutch engagement process. A two degree of model is presented in order to study effect of various clutch system components on its vibration performance. The judder is also affected by driveline inertial changes, variation in the coefficient of friction, μ , of the friction disc linings with slip speed, v , and the loss of clamp load. Hence, a non-linear multibody dynamic model of the clutch mechanism is also employed to study the effect of various clutch system and driveline components on the clutch actuation performance. The study on the results of the simulations show that various friction materials with different $\mu-v$ characteristics and loss of clamp load relating to the speed of clutch actuation contributes to judder.

KEYWORDS: Clutch, Judder, Friction Lining Material Characteristics, Two Degree of Freedom, Dynamic Model, Torsional Vibrations, Driveline

I. INTRODUCTION

There are two different types of chatter vibrations that can occur:

1) Self-induced chatters (friction vibrations):

A friction coefficient change with regard to the slip speed causes self induced chatter. A vibration can thus only occur when the dynamic friction coefficient is lower than the static friction coefficient or the dynamic friction coefficient drops with increasing slip speed, because otherwise a stationary balance develops.

2) Pressure-induced chatters:

Pressure-induced chatter is the result of an outside impulse source with periodic excitation. A periodically changing normal force affects the body. The pressure-induced chatter can also occur with neutral friction coefficient behavior, because it is excited by outside force modulation. The damping effect of the friction coefficient increasing with the slip speed naturally occurs again, because it counteracts an increase of the vibration amplitudes near the resonance.

II. LITERATURE REVIEW

An investigation of the torsional vibration mode of the clutch system, referred to as judder is presented by D. Centea and H. Rahnejat [1]. A nonlinear multi-body dynamic model of the clutch mechanism is presented in order to study the

effect of various clutch systems and driveline components on its vibration performance. The paper demonstrates that propensity to judder is related to the various friction lining material's characteristics. A Crowther and N Zhang investigates clutch engagement judder and stick-slip analytically and numerically to examine the influencing factors on these phenomena [2]. Degradation models expressing the evolutions of the friction model parameters are also proposed, where the structure of the degradation models is inspired from experimental results obtained in the earlier work. This way, the engagement dynamics of the clutch system during the useful lifetime can be simulated [3]. In the study of clutch vibrational and dynamical behavior, an SAE2 test setup mathematical model based on extended reset-integrator friction model was developed by Shoaib Iqbal, Farid Al-Bender. In order to take into account the different phases of fluid lubrication during engagement cycle, the model includes the experimentally determined Stribeck function. In addition the model considers the viscous effect and the delay in the actuation pressure signal. The model is validated with the experiments performed on the SAE2 test setup in both time and frequency domains. By analyzing the set of experimental results, we confirmed that the amplitude of judder vibration is independent of the amplitude of applied contact pressure fluctuation [4]. In the paper of W. Ost, P. De Baets and J. Degrieck both SAE#II and pin-on-disk tests are used to investigate the wear and friction characteristics of the friction material. He concluded that frictional vibrations occur in the presence of low drivetrain damping values and a negative gradient of the coefficient of friction [5].

III. TORSIONAL VIBRATION OF CLUTCH

The engine to the wheels through the flywheel, clutch and the driveline transmits the energy necessary for the motion of a vehicle. The clutch takes the energy from the flywheel and transmits it to the driveline. During the engagement process, on the friction surfaces of the clutch the friction torque acts as an engaging force for the driveline. A part of the energy transmitted through the driveline is transformed into other forms of energy by positive damping effects. If for some reason the damping becomes negative, a part of the energy transmitted by the clutch could induce self-excited torsional vibrations of the driveline, contributing to judder.

In the Coulomb friction region, the friction torque, M_f , can be defined as,

$$M_f = 2F_f R = 2\mu F_n R$$

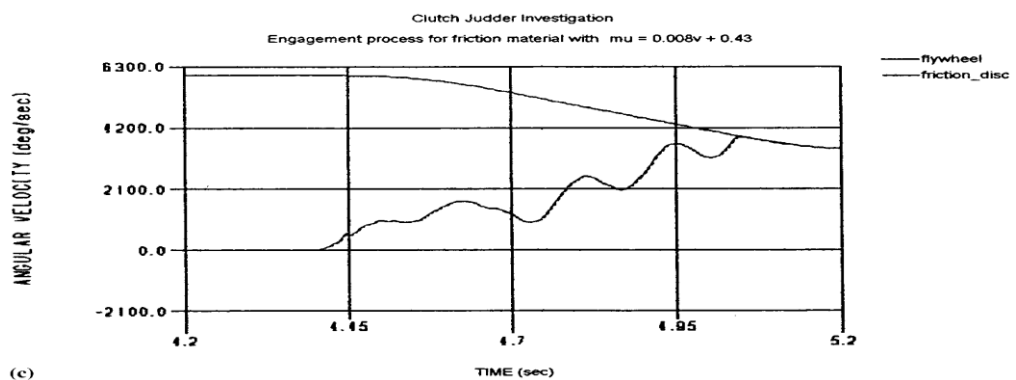
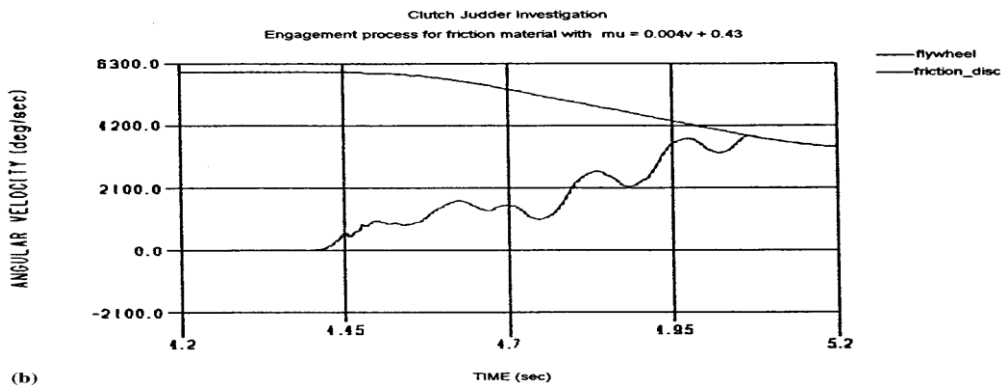
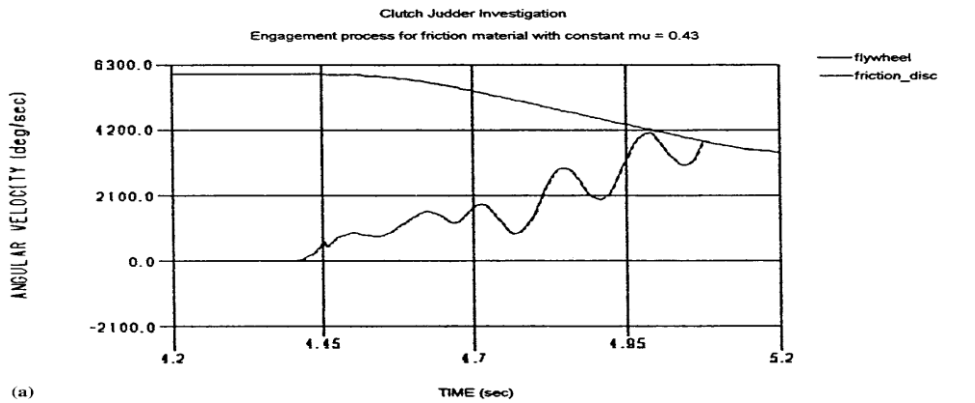
The damping coefficient of the driveline can become negative only if the friction torque has a variation caused by changes in μ , F_n or R . For a constant mean friction radius, the torsional vibrations of the driveline can be caused by a loss of clamp load or by variations in the interface coefficient of friction. For a constant clamp load, a cause of variation for the friction torque is the change in the value of the coefficient of friction during the engagement process.

IV. COMPUTER SIMULATION PROGRAM

Using study of the mathematical model developed above, a computer program was intended to analyze actions of system during one engagement cycle. The software used for programming was MATLAB/SIMULINK which evaluated a system of nonlinear differential equations. The output of program was plots of velocities of both inertia and engagement torque during engagement cycle. The model of the clutch engagement, built in order to study the take-up judder problem, is a multibody nonlinear dynamic model. The non-linear multibody model is also therefore employed to verify the behaviour of various measured friction material characteristics in the occurrence of judder, in conjunction with driver behaviour during the engagement process. Practical positive and negative gradients of the coefficient of friction with slip speed, obtained through experimental measurements, are considered.

V. RESULT

The results of the analysis carried out using a constant value of 0.43 for the coefficient of friction as shown in fig There are some torsional vibrations of the driveline at a frequency of around 7 Hz (this also being the same frequency obtained experimentally for the modelled 'judder vehicle').



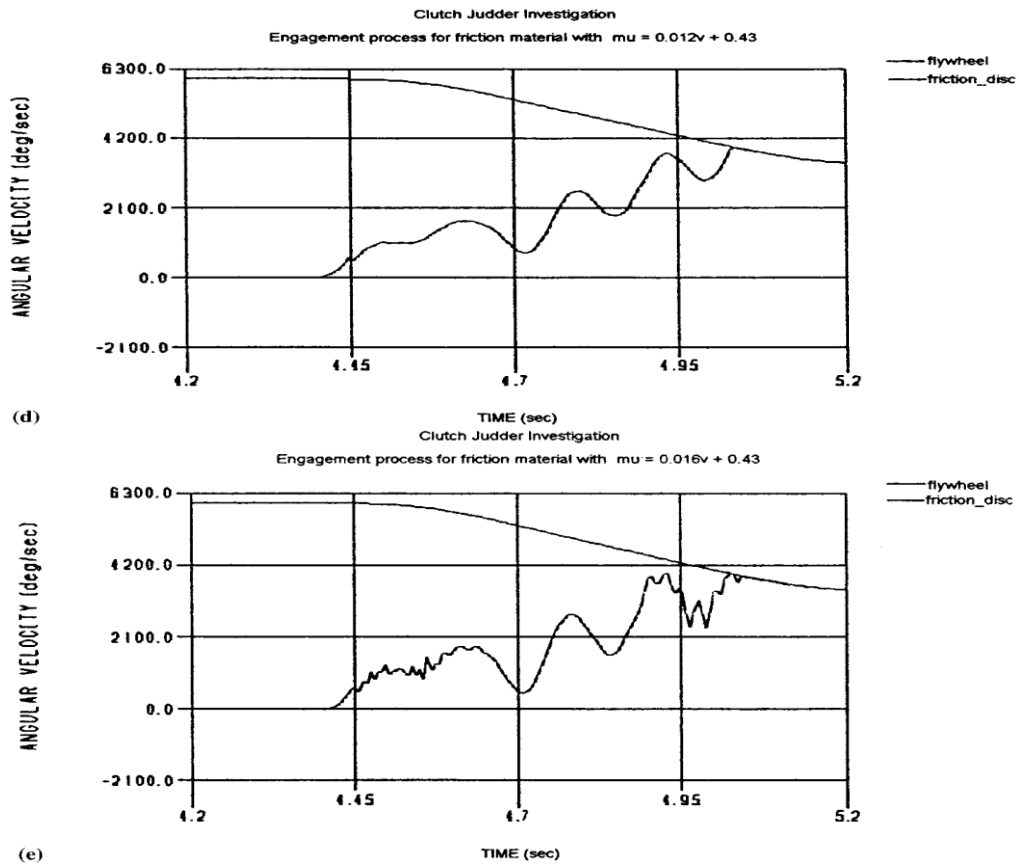
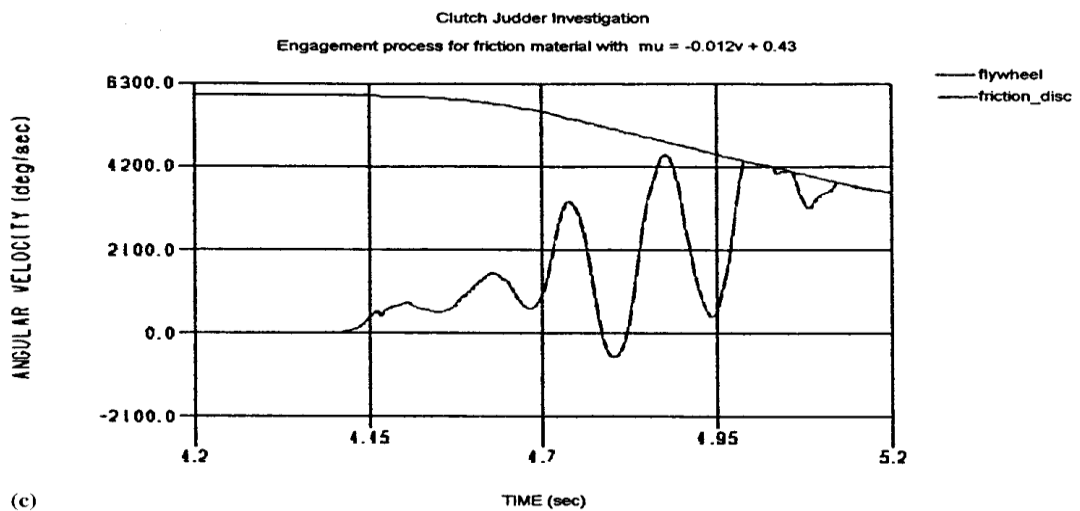
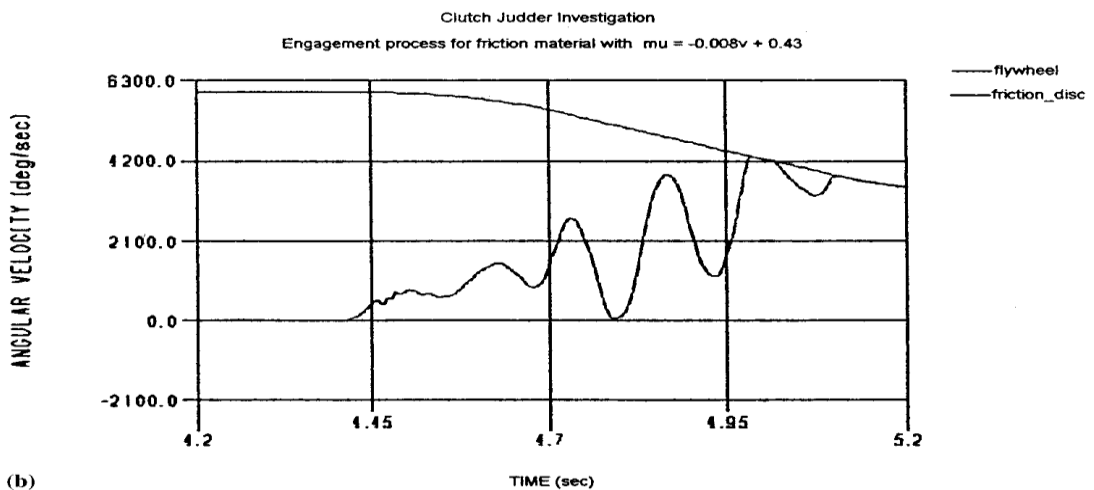
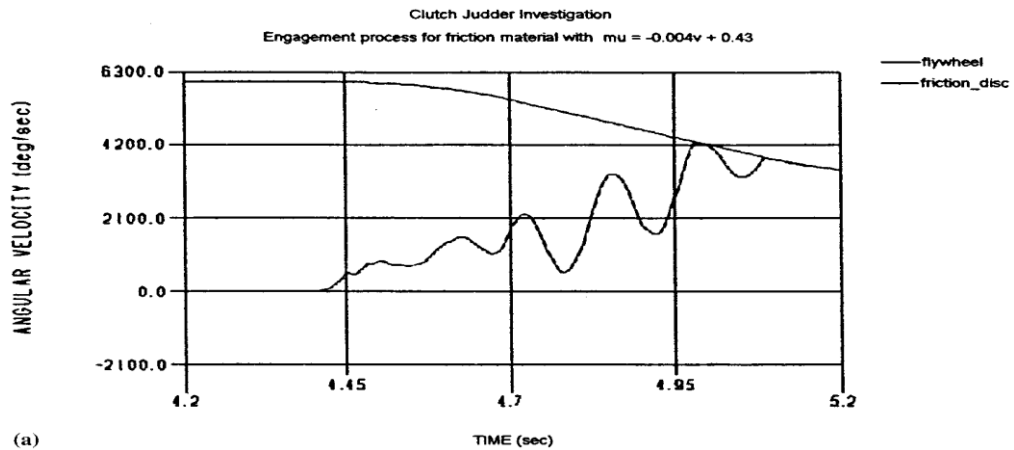


Figure 1: Engagement process for a material (a) with a constant coefficient of friction of 0.43 and with a coefficient of friction with a positive gradient of (b) 0.004, (c) 0.008, (d) 0.012 and (e) 0.016 s/m

The simulations obtained for higher positive gradients of the coefficient of friction [0.008 s/m (see Fig. 1c) and 0.012 s/m (see Fig. 1d)] do not exhibit any significant improvement when compared with a positive gradient of 0.004 s/m (see Fig. 1b). However, the results for the highest positive gradient exhibit a deviation from this trend. At first glance this deviation may be regarded as anomalous. However, it should be noted that the propensity to judder is also directly affected by the driver clutch actuation effort, affecting the clamp load application history.

The results of the analysis carried out using a constant value of 0.43 for the coefficient of friction as shown in fig. The amplitudes of oscillations are considerably larger than those for the case of a constant coefficient of friction (see Fig. 1a), indicating a strong tendency to judder. The oscillations that occur in the engagement process can be seen in any part of the driveline modeled. The vehicle undergoes torsional oscillation at tyre contact patches at the same frequency of 7 Hz. These vibrations will also be felt by the driver and physically occur under judder conditions.



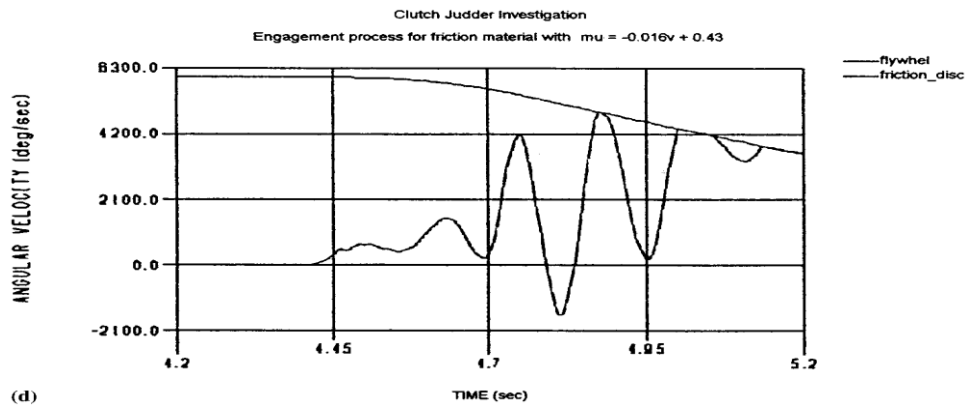


Figure 2: Engagement process for a material with a coefficient of friction with a negative gradient of (a) -0.004, (b) -0.008, (c) -0.012 and (d) -0.016 s/m

The simulations obtained for negative gradients of the coefficient of friction [-0.008 s/m (see Fig. 2b), -0.012 s/m (see Fig. 2c) and -0.016 s/m (see Fig. 2d)] show that the amplitude of the torsional vibrations of the driveline occur around 7 Hz during the engagement process and increase with larger negative values of the gradient of the coefficient of friction with slip speed.

Effect of Inertia of Inertia Discs

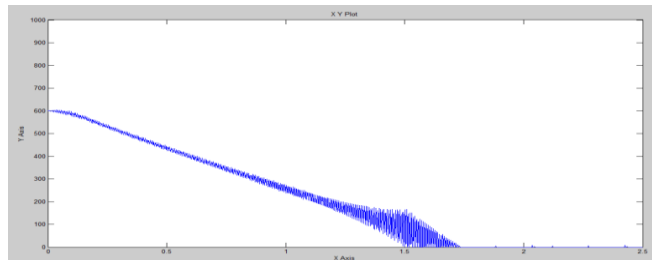


Figure 3: Facing disc velocity Vs time

Figure 3 shows effect of effect of inertia of inertia discs on performance of clutch. With decreasing inertia of inertia discs, amplitude of vibration and engagement time decreased. Frequency of vibration remains constant hence it does not have any effect of inertia of inertia discs.

Effect of Inertia of Facing Discs

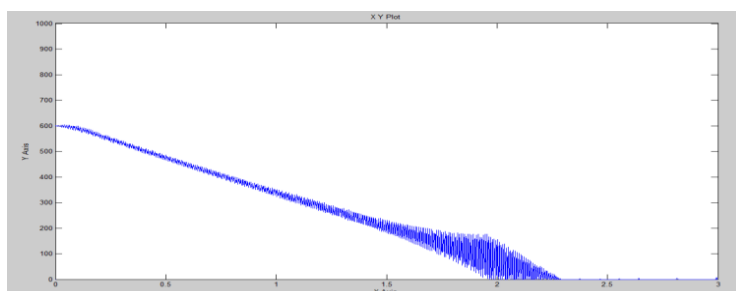


Figure 4: Facing disc Velocity Vs Time

Figure 4 shows effect of effect of inertia of facing discs on performance of clutch. Facing discs inertia has no effect on engagement time as engagement time remains same with increasing inertial of facing discs. On the other hand, increasing inertia of facing discs reduces frequency of vibration and also amplitude of vibrations.

Effect of Stiffness

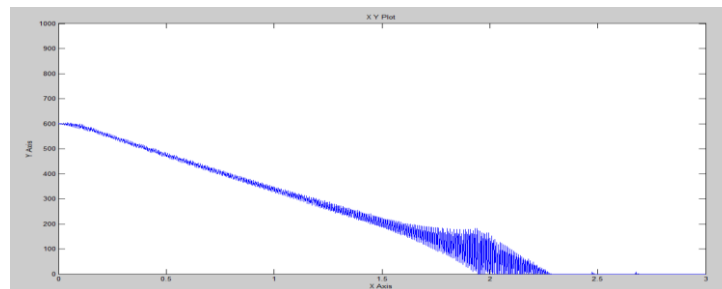


Figure 5: Facing disc velocity Vs time

Figure 5 shows effect of equivalent stiffness. Engagement time remains constant with change in stiffness. Frequency and amplitude of vibration decreased with decreased stiffness.

VI. CONCLUSION

From the study of mathematical model developed in this work , following conclusions are made.

- Relation between friction coefficient and relative velocity has big influence on vibrational performance of clutch.
- Friction material having negative rate of change of friction coefficient with relative velocity generates self excited vibrations in clutches.
- Clutch vibration performance is also dependent on clutch systems and driveline components.
- Judder can be initiated by the friction material characteristics owing to an overall reduction in the driveline damping.
- A positive gradient of coefficient of friction with slip speed provide a better damping effect and little or no self-excited vibrations occur.

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