An Adaptive Optimal Process Control of Clutch for AMT with the Use of ADAMS

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Abstract

A dynamic model of a manipulative machine for automobile clutch is setup in ADAMS and further analysis is made to an automatic clutch for AMT. Since the engaging process of clutch is complex and related to riding performance and life span of friction plate, it has to be researched intensively using modern control theory. Adaptive control is effective to avoid engine flameout, which guarantees successful power transmission. Optimal process control can achieve quality engagement given attention to riding performance and life span of friction plate. The function builder and control module of ADAMS provide convenience to model, control and verify the adaptive optimal control strategy for automatic clutch in visual prototyping.

Keyword: AMT automatic clutch, optimal control, model reference adaptive control

Introduction

Automatic Mechanical Transmission (AMT) has been a hotspot in automatic transmission field in recent years. The control for clutch engagement is the key to AMT. A membrane spring clutch is considered in this paper. The difficulty in research on electronically clutch unit (ECU) lies in two, (1) prediction of engine state; (2) optimal engaging law compromising riding performance and life span of friction plate. To verify a control strategy, a lot of experiments using actual vehicle should be performed unless visual prototype experiments is possible and reliable. ADAMS provides a round tool for its function builder and control module.

Compared with other kinds of ordinary spring, diaphragm spring (DS) has nonlinear elastic characteristic, which effectively avoids disengage force increasing due to normal wear. And it needs for disengage force almost the same as engage force instead of much larger when coil spring is used. The geometry of a membrane spring is simple but its elastic characteristic is complex, which is described in function builder.

The engine output performance is nonlinear with respect to throttle angle and its revolution. The relationship between its stable and dynamic performance has been studied. Thus the engine output performance is described by building 3-D splines in data element. The prediction of the engine state is carried out by model reference adaptive control strategy.

The model is set up involving engine, membrane spring, friction plate, manipulative mechanism, clutch parts, shock absorber, gear box, tire and etc.. The visual model is verified by actual experiments, which guarantee correctness and reliability for further control and analysis using ADAMS model. According to minimum theory, an optimal control is performed to achieve compromising optimal performance, that is, less lash and less wear. Synthesizing the above model reference adaptive control for engine and optimal control for riding and life, an accurate control law is worked out.

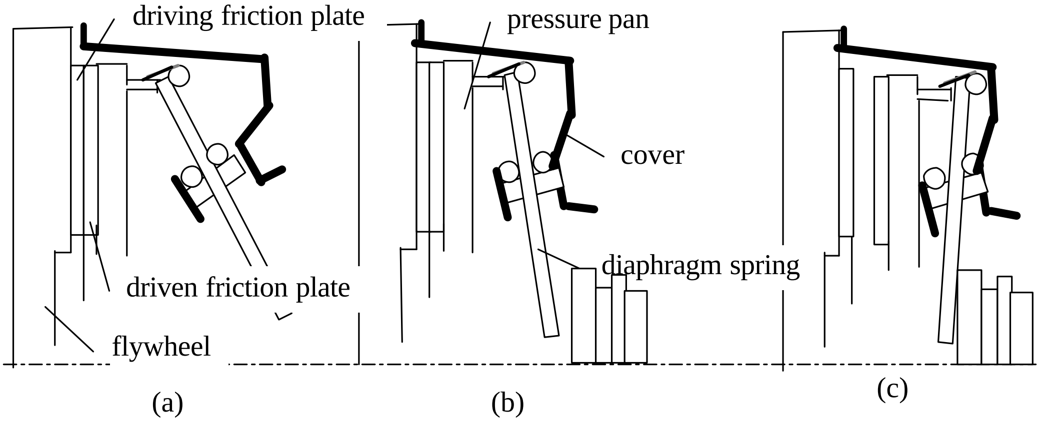
Several representative working condition is simulated, such as startup from standstill on ramp. In the end, conclusions are drawn.

objective system

The objective of the simulation is a diaphragm spring clutch and its manipulative mechanism installed in Santana LX.

There are mainly two groups of components in this system, listed as following:

1. **driving part**
   - (1) flywheel, standing for output of engine and acting as input to this system;
   - (2) cover of clutch;
   - (3) driving friction plate, passing torque to driven part by friction torque, acting as resistance to driving part during engaging process;
2. **driven part**
   - (1) driven friction plate, driving the transmission by friction torque;
   - (2) pressure pan, transmitting force from spring to driven friction plate by mean of pressing on the surface of driven friction plate;
   - (3) output shaft, simplifying the whole of gearbox and other mechanism related to it;
   - (4) diaphragm spring, creating pressure on the pressure pan due to deformation, which takes advantage of its nonlinear load-force characteristics;



Fig,.1 Operating principle of clutch

In view of vibration, springs and damping rubbers are installed between driving and driven friction plates and distributed in a circumference.

Before the dynamic model is constructed, it is necessary to illustrate the clutch working principle, which concerns about 3 stages. As in figure 1 (a), the cover is some distance from flywheel and the diaphragm spring is free without any load. In figure 1 (b), when the cover is fixed to the flywheel, the steel support ring pressed DS resulting in deformation (cone angle gets smaller). Thus, load exists on the outer end of the DS, which means that pressure is acting on pressure pan, then driven plate, driving plate in turn, therefore, power is passed from engine to gearbox. The above expresses the engagement stage. Figure 1 (c) denotes the disengagement stage. The separate bearing moves towards left. Since DS is fixed with clutch cover by hinges, which make up a steel support ring of the DS, and it can be regarded as pivot for the radial cross section of DS rotates around it, the DS appears a reverse cone. Thus, its outer end moves towards right to separate the driven friction pan from driving part.

Mechanics characteristic of DS

Because dynamical simulation of clutch is focused on the creation and transmission of force or torque, it is very important to be familiar with the characteristics of DS and its action mode. As to its advantages, firstly, it can act as both pressure spring and separate lever by itself, which simplifies the structure, makes it lighter and shortens the dimension apparently. Secondly, it contacts with pressure pan on a whole circular surface, which results in even distribution of pressure, fine contacts between friction plates and even wear. And to be our most interests, its nonlinear characteristic is superior to ordinary spiral spring.

In disengagement stage, both the two parts are loaded. During engaging, the diaphragm works from disengagement to engagement stage. Loads at either the outer end or the internal end, which are applied simultaneously, have different mechanics characteristics denoted by force following deformation. By educing from A-L technique, the characteristics is

$$F_1 = \frac{pEt \ln \frac{R}{r}}{6\left(1-m^2\right)\left(L-l\right)^2}\left(l_{11b} - k_L l_2\right)\left[\left(h - k_1 l_{11b} + k_1 k_L l_2\right)\left(h - 0.5 k_1 l_{11b} + 0.5 k_1 k_L l_2\right) + t^2\right]$$

in which,

R :outer radius of membrane spring; r :inner radius of membrane spring;
E : elastic module; m : Poisson coefficient;
h : inner cone height; t : plate thickness;
L : outer load radius; l : inner load radius;
l_{11b} : distortion of outer end in engagement stage; r_F :inner load radius;
k_L : the arm ratio of force; $k_L = (L-l)/(L-r_F)$; $k_1 = (R-r)/(L-l) > 1$

The above deduce process is complemented by built-in functions in ADAMS.

ADAMS Model

The kinematics connections and mechanics constraints are shown in Fig.2. To judge the contact, the impact function of ADAMS is used, and to define the contact friction force, the step

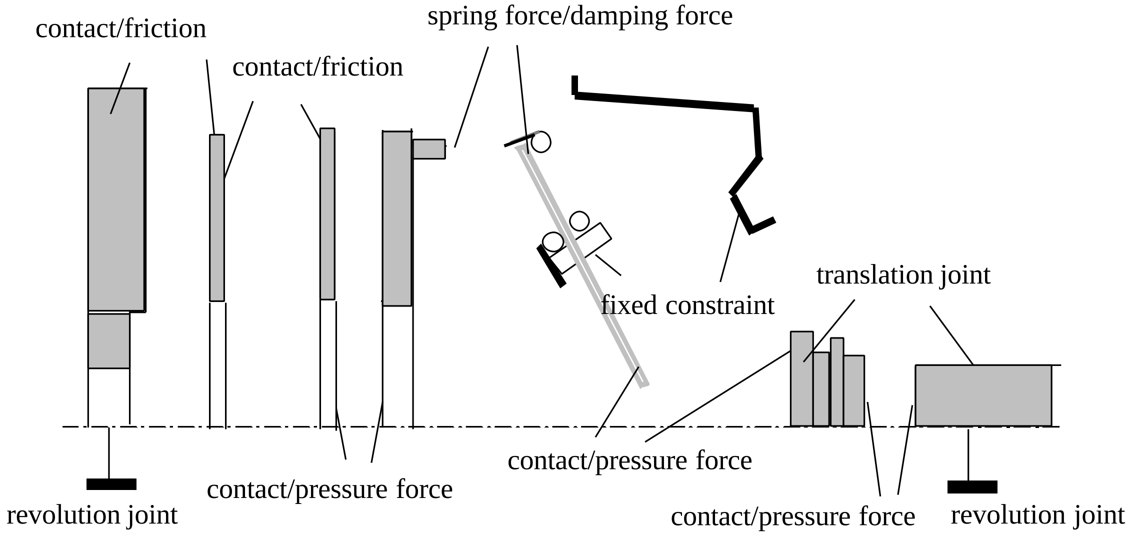


Fig.2 Kinematics connections and mechanics constraints

function is used, denoted in Fig.3. The full model of clutch and its correlative mechanism are shown in Fig.4.

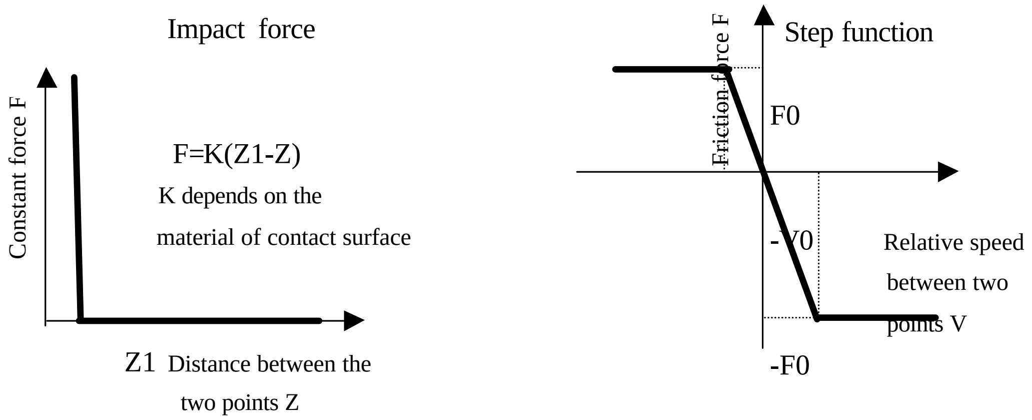


Fig.3 The impact force and step function to define the contact formalism

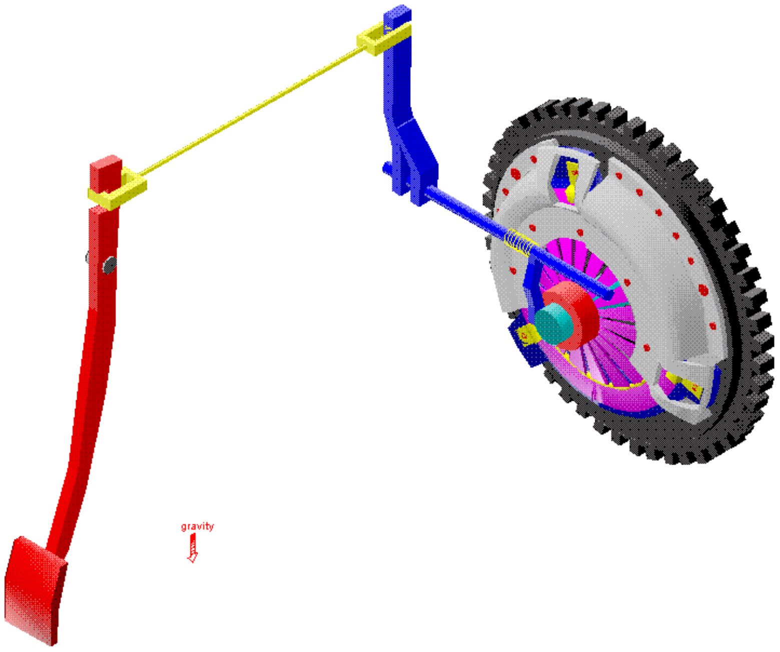


Fig.4 dynamic model in ADAMS/View

Control strategy

The control strategy is synthesized by optimal process control and model reference adaptive control. At first, the controller collects information of gear ratio and load, then begins to optimal control. Secondly, the

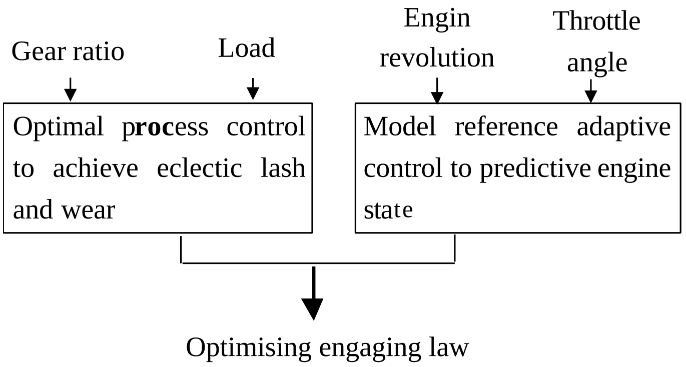


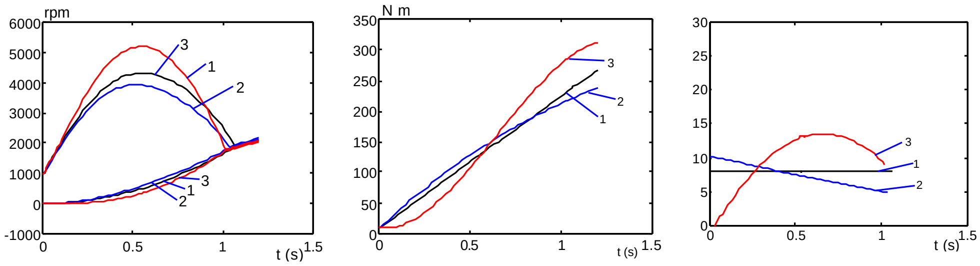
Fig.5 Control strategy for automatic clutch for AMT

information of engine revolution and throttle angle is collected, then a model reference adaptive control is performed to perdictive engine state. The whole controller is carried out using the interface between ADAMS 9.1 and MATLAB 5.1.

simulation results

1 Compare of different engagement rules on flat road

Because of the nonlinearity elastic of the membrane spring, the course of friction torque is different from the clutch pedal. In general, the driver releases the clutch pedal in a normal or parabola velocity. Compared with optimal control, visual experiments are made to simulate three types of manipulation in ADAMS/View. Curve 1 denotes the normal one, curve 2 denotes the parabola one and curve 3 denotes the optimal one. We can see, the normal one exceeds the limitation $10\, m/\sec^3$ of lash on initial stage while the parabola one exceeds the limitation on anaphase. Moreover, curve 2 shows larger increment of engine revolution which results in larger wear and shorter life span. In a word, the optimal one can meet the standard of riding performance and life span. It is proved that the optimal control is effective and ordinary driver can’t attain optimal quality unless dependence on automatic clutch actuator.



a) Synchronization trajectory of driving and driven shaft

b) Contrast between friction torque and carrying capacity of engine

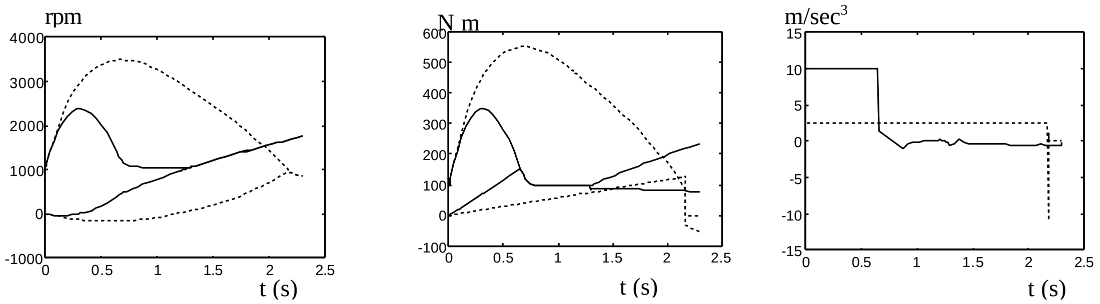
c) Course of lash level

1: optimal control law; 2: normal one; 3: parabola one

Fig.6 Compare among different engagement rules

2 Compare of different engagement rules on ramp

As we all know, the resistance torque on ramp is much larger than flat road. If the engagement is too fast, the engine is tend to be flameout, otherwise, the engine is tend to fly out. Since it is difficult for the driver to manipulate while startup on ramp, it is a model condition to verify the performance of adaptive optimal control of automatic clutch. In Fig.7, dashed lines are denoted ordinary linear engagement law without adaptive monitor control for engine. Although friction torque increases slowly which means the driven shaft speeds up slowly, the friction torque exceeds the carrying capacity of engine. So engine flameouts, startup on ramp fails. To make the



a) Synchronization trajectory of driving and driven shaft

b) Contrast between friction torque and carrying capacity of engine

c) Course of lash level

dashed lines: ordinary linear engaging process; real lines: adaptive optimal engaging process;

Fig.7 Control of clutch engagement while startup on ramp matter worse, the engine revolution increases rapidly, so the gap between the driving plate and driven plate is larger which results in more wear. Real lines denote the results of adaptive optimal control. On initial stage during engaging, the carrying capacity of engine is strong, so rapidly engaging is performed. Yet on latter stage, the engine is weaker, then the engaging velocity is adjusted in order to guarantee the engine working in gear. We can see in Fig.7, the engaging time of optimal control is much shorter, its lash level is less than $10 m/\mathrm{sec}^3$. Moreover, the wear is less for lower engine revolution. So all of the performance indexes are met, which means the controller is effective and practicable.

summary

The clutch engaging process, which is difficult to measure by an experimental approach, has been simulated in ADAMS and the following results were found:

(1) The ADAMS model for accurately simulating all gear shifting mechanism was created;

(2) By applying the calculated results to the solid model, the movement of the clutch system components was visualized;

(3) By utilizing the built-in functions, complex form of contact and force can be modeled accurately, moreover, control algorithm can be realized in time when dynamical simulation is going on.