Abstract: A method is provided for controlling a clutch in a transmission system. The clutch is controllable with a control signal to selectively assume one of an open operational mode, a controlled slipping operational mode and a locked operational mode. The method comprises using a feedback control component to generate a control signal that maintains the clutch in a stable, slipping operational mode, assess at least a first representative value of said control signal and a second representative value of a transmission fluid temperature in the clutch while maintaining the clutch in said stable, slipping operational mode; using an open loop control component to generate a control signal that maintains the clutch in the locked operational mode, wherein the control signal provided by the open loop controller at least depends on the assessed first and second representative values.

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Title: Control apparatus for a clutch in a power train and method for controlling a clutch in a power train as well as a power train including the control apparatus

BACKGROUND

The present invention pertains to a control apparatus for a power train.

The present invention further pertains to a method for controlling a power train.

The present invention still further pertains to a power train including the control apparatus.

A power train in a continuously variable transmission typically includes a torque converter / lock-up clutch (TC/LUC), a drive-neutral-reverse clutch (DNR) and a variator. The variator is typically provided as a transmission belt that mechanically couples two pulleys. In normal driving stages all elements of the power train preferably operate in a non-slipping operational mode as a slipping operation would entail energy losses and therewith negatively affect fuel econom. A slipping operational mode of the variator should particularly be avoided as this results in wear of the transmission belt and/or the pulleys. This can be achieved by high clamping levels. On the other hand clamping levels, in particular a clamping level of the transmission belt should not be set too high because this would imply an unnecessarily high drive current is supplied by the charging system to maintain this high clamping level, which also is unfavorable for fuel economy. Additionally increasing the clamping level above a level necessary for slip free operation of the variator tends to increase transmission losses of the variator and an increased wear of the variator due to an increased friction. Furthermore, it should be taken into account that the driving conditions may change suddenly, for example by damages of the road or by a rapid braking of the vehicle. To avoid a slipping of the variator in such
situations a LUC torque capacity should be set to a value that is lower than a torque capacity of the variator. Therewith it is achieved that in case of an unexpectedly high torque to be transferred, the TC/LUC serves as a fuse that absorbs the unexpected torque by slipping, therewith avoiding a slipping of the variator. The LUC, usually designed as a wet clutch, is capable to operate in a continuous slipping operational mode without damage. The response characteristics of elements in the power train are also dependent on their operation temperature. These may strongly vary, dependent on a time lapsed since activation of the vehicle. In particularly for the clutches this strongly depends on their operational mode. In a slipping operational mode the operational temperature strongly increases as a result of energy dissipation. The response characteristics of a clutch may also depend on other conditions. Moreover the response characteristics change over time as a result of wear during use.

SUMMARY

It is a first object to provide a control apparatus that enables a proper control of a clutch taking into account temperature variations and changes of its characteristics during lifetime.

It is a second object to provide a power train including the improved control apparatus.

It is a second object to provide a control method that is arranged to control a power train in this manner.

In accordance with said first object a control apparatus is provided as claimed in claim 1. The control apparatus as claimed is configured for controlling a clutch in a transmission system for example a lock-up clutch as used in a torque converter lock-up clutch assembly, or a clutch used in a drive neutral reverse DNR assembly. The clutch is controllable with a control signal from the control apparatus to selectively assume one of an open operational mode, a controlled slipping operational mode and a locked
operational mode. The control apparatus comprises an open loop controller with an emulation module and an update module to update the emulation module. The open loop controller determines a control signal to control the clutch based on estimated response characteristics of the clutch, for example based on manufacturer specifications. The control apparatus also comprises a feedback controller to provide a control signal component for controlling the clutch based on an observed response of the clutch. The observed response may for example comprise a slipping rate of the clutch. The feedback controller may further base its response on derived quantities such as an estimated value of a transferred torque.

It is noted that the feedback controller (also denoted as closed loop controller) and the feedforward controller (also denoted as open loop controller) may share certain components. For example the feedback controller and the feedforward controller may share an amplifier to provide a control signal of sufficient strength. As another example the feedback controller and the feedforward controller may share a selection element that selects a signal from a specific feedback element or a specific feedforward element. Accordingly the feedback controller and the feedforward controller may also be considered as one and the same controller, being in a feedback configuration (closed loop configuration) and a feedforward configuration (open loop configuration) respectively. Furthermore in the feedback configuration the control signal may be composed by superposition of a feedforward based component and a feedback based component.

The control apparatus has at least a first control mode wherein the feedback controller is enabled to generate a control signal that maintains the clutch in a stable, slipping operational mode according to predetermined specifications, for example a mode wherein a difference between the input rotational speed and the output rotational speed is maintained at a constant value, or wherein a ratio between the input rotational speed and the output rotational speed is maintained at a constant value. In this stable slipping
operational mode the control apparatus assesses at least a first representative value of the control signal with which it maintains that operational mode and also assesses a second representative value of a transmission fluid temperature in the clutch. The control apparatus uses the representative feedback signal value and the one or more respective representative state values such as the representative value of the transmission fluid temperature to update the emulation module.

The control apparatus further at least has a second control mode wherein the feedback controller is disabled and wherein the open loop controller generates a control signal that maintains the clutch in the locked operational mode, wherein the control signal at least depends on the assessed first and second representative values. I.e. the control signal has a value dependent on a emulation signal value of an emulation signal generated by the updated emulation module dependent on an actual value of said one or more clutch state signals.

In an embodiment of the control apparatus the feedback controller comprises an integral action control component and the representative feedback signal value is determined with said integral action control component. This is advantageous in that the value of the output signal provided by the integral action control component is directly available as an average value that is representative for the feedback signal value.

In an embodiment the emulation module is updated in the first control mode to reduce a difference between a value of the emulation signal associated by the emulation module with said one or more respective representative state values and the characteristic feedback control signal value. The associated value is the value of the emulation signal generated by the emulation module on the basis of the respective representative state values. I.e. this is the value which according to the current state of the emulation model as implemented in the emulation module would be necessary to obtain the controlled slipping operational mode. This may be a
value of the control signal to set the clutch in its controlled slipping
operational mode or may be a value with which another signal has to be
modified to obtain the value of the control signal that is expected to set the
clutch to its controlled slipping operational mode. The characteristic
feedback control signal value indicates the signal value of the control signal
for which the controlled slipping operational mode was actually observed or
the signal value that had to be added to the another signal to obtain the
value of the control signal for which the controlled slipping operational
mode was actually observed.

In an embodiment the difference is partly reduced when updating. I.e.
the updating takes place in a conservative manner so that fluctuations in
the observed signals do not result in an unstable behavior of the controlled
clutch.

According to a second aspect, an improved power train for use in a
continuously variable transmission system is provided that includes a
torque converter / lock-up clutch (TC/LUC), a drive-neutral-reverse clutch
(DNR) and a variator. The improved power train may comprise an
embodiment of the control apparatus as claimed to control the lock-up clutch
and/or an embodiment of the control apparatus as claimed to control the
DNR clutch.

According to a third aspect a method is provided for controlling a
clutch in a transmission system, the clutch being controllable with a control
signal to selectively assume one of an open operational mode, a controlled
slipping operational mode and a locked operational mode, the method
comprising:

in a closed loop control mode generating a feedback control signal
that maintains the clutch in a stable, slipping operational mode based on an
observed response of the clutch;

assessing a representative control signal value of said feedback
control signal with which the clutch is maintained in said stable, slipping
operational mode signal as well as one or more respective representative state values for one or more clutch state signals indicative for a state of the clutch; updating an emulation model indicative for estimated response characteristics of the clutch based on the assessed representative control signal value and the one or more respective representative state values;

in an open loop control mode, using the updated emulation model to generate an open loop control signal as a function of respective actual values of the one or more clutch state signals to maintain the clutch in its locked operational mode.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other aspects are described in more detail with reference to the drawings. Therein:

FIG. 1 schematically shows a power train in a vehicle;

FIG. 2 shows in more detail aspects of a control apparatus;

FIG. 3A illustrates an embodiment of the control apparatus in a first control mode;

FIG. 3B illustrates the embodiment of the control apparatus in a second control mode;

FIG. 4 illustrates a first embodiment of a method of controlling a clutch;

FIG. 5A-5E depicts various signals and state indicators during execution of the first embodiment of the method;

FIG. 6A illustrates another embodiment of the control apparatus in a first control mode;

FIG. 6B illustrates the another embodiment of the control apparatus in a second control mode;

FIG. 7 illustrates a second embodiment of a method of controlling a clutch;
FIG. 8A-8F depicts various signals and state indicators during execution of the first embodiment of the method.

DETAILED DESCRIPTION OF EMBODIMENTS

FIG. 1 schematically shows a power train in a vehicle to transfer power from a power source 10, such as a combustion engine or an electric motor, to wheels 70 of the vehicle. The power train as shown in FIG. 1 comprises a torque converter/lock-up clutch (TC/LUC) 20, a drive-neutral-reverse clutch (DNR), a variator 40, a fixed gear 50, and a differential 60. The TC/LUC 20 couples an output axis of the power source 10 to the DNR 30, with a controllable slip rate and torque ratio, i.e. the ratio between the transmitted torque at its output and the torque received at its input from the power source 10. The DNR clutch 30 is provided to couple the TC/LUC 20 to the variator 40. The DNR clutch 30 is controllable to assume one of a drive operational mode D corresponding to driving the vehicle in a forward direction, a reverse operational mode R, wherein the vehicle is driven backward and a neutral operational mode wherein it keeps the variator 40 decoupled from the TC/LUC 20. The variator 40 transmits the power delivered from the DNR clutch 30 via the fixed gear 50 and the differential 60 to the wheels 70, at a gear rate that can be selected from a continuous range.

In the embodiment shown a setting or operational mode of the torque TC/LUC 20, the DNR 30, and the variator 40 is determined by hydraulic signals, i.e. a pressure of an hydraulic fluid. The hydraulic signals are generated by a hydraulic control unit (HCU) 80, which is supplied with a supply flow Pe0 by a pump 85. In the embodiment shown the operational mode of the TC/LUC 20 is controlled by hydraulic pressure P20, the operational mode of the DNR clutch 30 is controlled by hydraulic pressures P32 and the operational mode of the variator is set by hydraulic pressures P41 and P42. To that end a hydraulic control unit 80 is provided that on its turn is controlled by transmission control unit (TCU) 100. Alternatively the
operational mode of the various power train elements may be controlled by electric signals, for example using electro-magnetic actuation elements. The TCU 100 is further coupled, e.g. via a bus, here a CAN-bus 95, to an engine control unit 90. The TCU is further configured to receive input signals from various inputs, such as a turbine speed signal (the output rotational speed of the TC/LUC), a primary pulley rotational speed, corresponding to the DNR output speed, a secondary pulley rotational speed at the output of the variator 40, a secondary pulley pressure and an oil reservoir temperature. Other input signals, for example from a throttle pedal, a brake pedal (not shown) and sensor elements, e.g. speed sensors, temperature sensors, torque sensors and the like (not shown) may be received and monitored by the engine control unit 90 and passed on to the TCU 100 via the CAN bus 95.

FIG. 2 schematically shows a control apparatus 100 comprising a controller CCL for controlling a clutch CL in a transmission system. The controller CCL is configurable as an open loop controller and as a closed loop controller. The clutch CL is controllable with a control signal $P_{\text{set}}$ to selectively assume one of an open operational mode, a controlled slipping operational mode and a locked operational mode. In practice a hydraulic system is present that converts the control signal, which typically is a low energy signal into a signal that is capable of actuating the clutch, for example as an electrical signal that actuates the clutch by electromagnetic forces, or a hydraulic pressure that causes a hydraulic actuator to actuate the clutch. In other embodiments an amplifier may be present that amplifies the control signal and that uses the amplified control signal to generate a hydraulic pressure to actuate the clutch. In order not to distract from the essential features of the present controller, these details are ignored here. For now it is merely essential that the clutch CL is responsive to the control signal $P_{\text{set}}$, and that the response characteristics may change in time due to a wear of the clutch and also are dependent on an operation temperature.
T\textsubscript{CL} of the clutch, in particular an operation temperature of a hydraulic liquid present therein.

As shown in FIG. 2 the controller C\textsubscript{CL} comprises an open loop controller OLC to determine a control signal component P\textsubscript{f} for controlling the clutch CL based on estimated response characteristics of the clutch. The response characteristics may be estimated on the basis of specifications provided by the manufacturer and the prevailing temperature of the clutch. The open loop controller OLC, i.e. the controller C\textsubscript{CL} configured in an open loop control configuration, comprises an emulation module 124 that generates the control signal component Pf based on an input control signal S\textsubscript{OLC} from the main controller 110 and an input signal that is indicative for an actual temperature T\textsubscript{CL} of the clutch.

The controller C\textsubscript{CL} also comprises a feedback controller CLC, i.e. is configurable as a feedback controller, to provide a feedback control signal component P\textsubscript{c} for controlling the clutch based on an observed response of the clutch CL. In the embodiment shown the observed response is a slip rate ns, as determined by a slip detector 116. The feedback controller CLC further comprises a comparator 111 for comparing a required response, e.g. a specified slip rate, with the observed response and to provide an error signal indicative for the difference. The feedback controller CLC further comprises a control signal generator 112 to generate a feedback control signal component P\textsubscript{c} based on the error signal e. The control signal generator 112 may for example comprise one or more of a proportional component, an integrator component and a differentiator component.

The controller C\textsubscript{CL} further comprises a combination component 113, which dependent on a control signal S113 from the main controller 110, may select the feedback control signal component P\textsubscript{c}, the open loop control signal component Pf or a combination thereof as the control signal P\textsubscript{set} to be provided to the clutch. A combinations control signal components P\textsubscript{c} and Pf
may for example be a (weighted) sum or a product of these signal components.

In the embodiment shown the main controller 110 also is provided to control other transmission system components T10, T40, T30, exchanging respective signals S10, S40, S30. The other transmission system components may for example include the engine 10, and the variator 40 and another clutch. For example if the clutch CL is the DNR clutch 30, then the other clutch to be controlled may be the lock up clutch in the torque converter and vice versa. The main controller 110 is responsible for a proper coordination in the manner in which the various components of the transmission system are controlled. For example the main controller 110 may control the transmission system such that the variator always has the highest torque capacity, so that sudden torque variations, e.g. due to bumps in the road are absorbed by a clutch and slip of the variator is avoided.

The controller CCL at least has a first operational mode wherein the feedback controller CLC is enabled to generate a control signal $P_c$ that maintains the clutch CL in a stable, slipping operational mode. A stable slipping operational mode is to say a slipping operational mode wherein the clutch transfers an at least substantially constant torque at an at least substantially constant slipping rate. This may for example be the case wherein an input of the clutch rotates with a constant velocity, and output of the clutch does not rotate, but exerts a predetermined torque, e.g. when a vehicle using the transmission system is kept at standstill. In another example the output of the clutch rotates, but at a lower rotational speed than the input while a substantially constant torque is transferred to maintain the vehicle at a constant velocity or accelerating at a constant rate. It is noted that minor variations are allowable for example variations in the transferred torque and in the slip rate that do not exceed 20% in a time interval of 20 ms.
While the feedback controller CLC maintains the clutch CL in the stable, slipping operational mode, the controller assesses a first representative value of the control signal $P_c$ with which it maintains this operational mode. The first representative value of the control signal $P_c$ may for example be the stabilized value of the control signal, for example the output provided by an integrator component of the control signal generator 112. The control signal may be considered sufficiently stabilized if variations therein are less than a predetermined threshold value, e.g. based on an estimated noise level for example a slip rate corresponding to zero slip or to a predetermined minimum amount of slip. If an integrator component is absent, it may be an average value. In an alternative embodiment a representative value may be estimated before stabilization, based on the estimate final value at which the control signal $P_c$ is expected to stabilize, taking into account a time constant determined by the elements in the closed loop. For example a value of the control signal may be assessed upon expiry of a predetermined time interval, for example a time interval having a duration of 2 or 3 times that time constant. Although the feedback component may still show variations exceeding the noise level the assessed value at that point in time may be used to estimate the value at which the control signal will stabilize. The controller assesses a second representative value of a transmission fluid temperature $T_{CL}$ in the clutch. Typically the transmission fluid temperature $T_{CL}$ will rise during this operational mode due to energy dissipation in the clutch. An average value of the transmission fluid temperature $T_{CL}$ during this first control mode of the controller may for example be the representative value. Alternatively, the representative value may be a value of the transmission fluid temperature $T_{CL}$ halfway the first control mode, or may be based on a measurement of the transmission fluid temperature at another point in time, which is corrected for changes due to energy dissipation.
The controller CCL further has a second control mode wherein the feedback controller CLC is disabled and wherein the open loop controller OLC generates a control signal Pf that maintains the clutch in the locked operational mode, wherein the control signal at least depends on the assessed first and second representative values. This functionality is schematically indicated by update module 120 to update the emulation module 124 based on the assessed representative values.

The open loop control signal generator 124 may for example comprise a prediction signal generator component that generates a prediction component based on specifications provided by the manufacturer of the clutch and an emulation module that provides for an adaptation to the prediction component based on input from the update module 120.

A first embodiment is described in more detail with reference to FIG. 3A and 3B. In the embodiment shown in FIG. 3A, the clutch CL is a DNR clutch 30. In the embodiment shown, the clutch CL is illustrated as a unit that further comprises a hydraulic actuation system that actuates the clutch 30 in response to the control signal Pset. In the embodiment shown the open loop control signal generator 124 is schematically illustrated as providing a prediction signal component Pkp. It may receive the value for the prediction signal component Pkp from an external source as shown in the drawing, or generate this signal internally. In this example the signal Pkp specifies the value of the control signal Pset that is expected to cause the DNR clutch to operate at its kiss-point in a new state of the clutch at the reference temperature. When operated at its kiss-point the DNR clutch transmits a low torque, differing from 0 however, that facilitates an acceleration from a standstill condition of the vehicle. The torque transferred in that operational mode of the clutch may be in the range of 1 to 10 Nm for example. The actual value of the control signal however depends on the temperature of the clutch, indicated as Toil and further the dependency changes during lifetime of the clutch 30. The open loop control
signal generator 124 further comprises an emulation module 126, to adapt the prediction signal $P_{K_p}$, so as to obtain the open loop control signal component $P_{K_p,adp}$. Update module 120 regularly adapts the characteristics of this emulation module 126 to take into account changes of this dependency. The emulation module 126 may for example include a lookup table that for each temperature range specifies a value for the adaptation signal $P_{adp}$. Each temperature range may for example a fixed range of 1-10 degrees, for example from 0 to 10, from 10 to 20 etc. Alternatively temperature ranges may have different sizes, for example larger sized temperature ranges may be used where the response of the clutch is less dependent on the temperature. In another embodiment the value for $P_{adp}$ is expressed as a mathematical function of the temperature value $Toil$, wherein the parameters of this function, e.g. a spline are adapted to meet observed characteristics.

A method of operation is now described in more detail with reference to FIG. 4 and FIG. 5A-5E as well as FIG. 3A, 3B. Therein FIG. 4 schematically illustrates steps of the method and FIG. 5A-5E illustrates signals occurring in the controlled transmission system as follows: FIG. 5A shows a binary signal that specifies whether or not (true/false) the calibration procedure can be initiated. FIG. 5B shows a (physical) operational mode of the DNR clutch. FIG. 5C shows a feedback control signal component, here the integrator component $Pi$ from a PID controller. FIG. 5D shows contribution $P_{adp}$ from the emulation module 126. FIG. 5E shows the temperature $Toil$ of the hydraulic transmission liquid in the clutch.

Returning now to FIG. 4, a verification step S0 is shown therein, where it is verified whether or not proper conditions prevail to perform a calibration procedure, i.e. a procedure wherein the emulation module 126 or an emulation model used in controlling the clutch is updated. In this step it
may be verified for example that the main controller 110 has controlled the transmission in an Idle-Neutral state. In this state the vehicle is at standstill, with the output shaft of the DNR clutch 30 in a non-rotating state and the input shaft of the DNR clutch 30 driven by the engine at a non-zero rotational speed with the engine 10 in a stationary operational state. It can be seen in FIG. 5A, 5B that this condition is not (yet) met at point in time to, as the DNR clutch 30 is in its open operational mode. Also it may be verified whether a predetermined distance was travelled since a previous execution of this method. Alternatively, this requirement may be overruled if abnormalities in the transmission system are detected. In other embodiments the method may be performed each time at standstill regardless the distance travelled. At point in time ti, the DNR clutch is set into a slipping operational mode with the vehicle at standstill, hence the rotational speed of the output shaft of the DNR clutch is still 0. In the Idle-neutral operational mode the main controller 110 is configured to keep the clutch in the TCLUC assembly in a fully opened operational mode. In this operational mode only a weak mechanical coupling is provided by the torque converter in the TCLUC assembly.

At this point in time ti it is confirmed that the required conditions are met in step so, and the feedback controller CLC is enabled in step Si to generate a control signal Pc that maintains the clutch 30 in the stable, slipping operational mode wherein the specified minimum amount of torque, for example in the range of 1 to 10 Nm is transferred to the output of the DNR clutch 30. The control mode of the controller in this step is schematically shown in FIG. 3B. In the example shown, the feedback controller CLC only provides the correction to the predicted value that is necessary to achieve the output signal Pset required to maintain the clutch in this operational mode. In other embodiments the open loop component 124 as shown in FIG. 3B may also provide the adaptation component Padp, and in that case the feedback controller CLC provides the correction signal
Pc to correct the signal Pxp_adp to achieve the kiss-point, as shown in FIG. 5C. After a predetermined time interval, at point in time t2, the correction signal Pc is stabilized, and a representative value Ci thereof is estimated in step S2. Also a representative value denoted as \( T_{\text{ol}}^* \) is determined of the temperature of the hydraulic transmission liquid. This may take place in a time interval \( t_2 - t_3 \), so as to determine an average value of the feedback control signal component and an average value of the temperature.

In step S3, the update module 120 updates the emulation module 126. For example by updating the lookup table value for the signal Padp for the temperature range relevant for the determined representative temperature \( T_{\text{ol}}^* \) with a new lookup table value determined by the representative value Ci of the correction signal. For example, if the representative value \( T_{\text{ol}}^* \) for the temperature is 73 degrees C the lookup table value for the range including this interval is updated. The previous value in the lookup table may for example be replaced with the representative value for the control signal, but alternatively, it may be replaced with a replacement value which is a linear combination of the previous value and the representative value. Alternatively, if the emulation module 126 calculates its output signal as a parametric function of the actual value for the temperature, the update module 120 may update the emulation module 126 by modifying the function parameters.

S4 in FIG. 4 is a waiting step, wherein a change of operational mode of the clutch from slipping to open or from slipping to closed is monitored.

If one of these operational mode changes is detected at point in time \( t_4 \), the clutch 30 is controlled by the open loop controller OLC using the updated emulation module 120.

FIG. 6A shows a second embodiment, wherein the clutch to be controlled is a lock-up clutch of a torque converter lockup clutch unit. As in the embodiment of FIG. 3A, the clutch CL is illustrated as a unit that further comprises a hydraulic actuation system that actuates the clutch 20
in response to the control signal Pset. Alternatively, another actuation system, such as an electromechanical actuation system may be used. As in the embodiment of FIG. 3A, the operation of the clutch 20 is dependent on its operation temperature. As a further complication it is a requirement that the torque Mi uc to be transferred should be controllable. In the embodiment shown the open loop controller OLC comprises a prediction signal generator PRD that generates a prediction signal Pf for example based on specifications of the manufacturer for the new product when operating at a reference temperature. The prediction signal generator PRD generates the prediction signal Pf using input signals M ref and n s,ref, for example provided by the main controller 110. The generated prediction signal Pf indicates the value which according to these specifications causes the clutch 20 to assume an operational mode wherein it is capable of transferring a torque Mref at a slip rate n s,ref. The emulation module 126 generates the emulation signal Padp, which adapts the prediction signal Pf to obtain the control signal Pset as a function of the transferred torque Mi uc and the actual prevailing temperature τ i uc of the clutch. The emulation module 126 may for example include a lookup table that for each combination of a temperature range and a torque range specifies a value for the adaptation signal P dp. Each temperature range may for example a fixed range of 1-10 degrees, for example from 0 to 10, from 10 to 20 etc. Alternatively temperature ranges may have different sizes, for example larger sized temperature ranges may be used where the response of the clutch is less dependent on the temperature. Likewise the torque ranges used may mutually have the same size or may have different sizes depending on the extent to which the required adaptation signal depends on the transferred torque. In another embodiment the value for P dp is expressed as a mathematical function of the temperature value τ o i and the transferred torque M i uc, wherein the parameters of this function, e.g. a spline are adapted to meet observed characteristics.
A method of operation in this embodiment is now described in more detail with reference to FIG. 7 and FIG. 8A-8F as well as FIG. 6A, 6B. Therein FIG. 7 schematically illustrates steps of the method and FIG. 8A-8F illustrates signals occurring in the controlled transmission system as follows:

FIG. 8A shows a binary signal that specifies whether or not (true/false) the calibration procedure can be initiated.

FIG. 8B shows a (physical) operational mode of the lockup clutch.

FIG. 8C shows a feedback control signal component, here the integrator component Pi from a PID controller.

FIG. 8D shows contribution $p_{\text{adp}}$ from the emulation module 126.

FIG. 8E shows the torque transferred by the clutch.

FIG. 8F shows the temperature $T_{\text{iu}}$ of the hydraulic transmission liquid in the clutch 30.

 Returning now to FIG. 7, a verification step S10 is shown therein, where it is verified whether or not proper conditions prevail to perform a calibration procedure. In this step it may be verified for example that the transmission system is operating under steady state driving conditions, such that the clutch 20 transfers an at least substantially constant torque at a substantially constant rotational speed. This for example the case if the vehicle is driving in a cruise control drive mode. Also it may be possible to perform the procedure if the vehicle is in a drive mode of constant modest acceleration while maintain the transferred torque at a substantially constant level. As long as the variations in the transferred torque and the rotational speed remain within predetermined bounds, e.g. do not deviate more than 20% from their average value it may be possible to successfully complete the procedure. It may alternatively possible to start the procedure without a precondition, but this has the disadvantage that the risk is high that the procedure is not successful. Also it may be verified whether a predetermined distance was travelled, or a predetermined period of time
lapsed since a previous execution of this method. Alternatively, this requirement may be overruled if abnormalities in the transmission system are detected. As shown in FIG. 8A, at point in time t10, this condition is not yet met, as it is detected that the transferred torque shows variations that exceed a predetermined limit.

In a subsequent step S11A, SUB, initiated at t11, a ramp down control signal $P_{\text{ramp}}$ is provided to cause a gradual transition of the clutch 20 from a locked operational mode of operation into a slipping operational mode wherein the LUC transfers a torque of predetermined value with a predetermined amount of slip. This is schematically illustrated in FIG. 6B. In this operational mode the difference between input rotational speed and output rotational speed is maintained at a constant value, for example a value in the range of 10 to 100 rpm, for example about 30 rpm.

Once this condition is detected, feedback control is enabled in step S12 to generate a control signal that maintains the clutch in a stable, slipping operational mode. In an exemplary embodiment, operation of the clutch 20 is considered stabilized in the specified slipping operational mode if the variance of the feedback control signal component $p_c$ within a predetermined time interval is less than a threshold value. For example it may be required that the difference between a highest and a lowest value of the feedback control signal component $p_c$ is less than 20% of an average value in the specified time interval, e.g. a time interval of 20 ms. In this example it is detected at point in time t14 that the feedback control signal component $p_c$, here $p_i$ remained within specified boundaries during the specified window of time. Presuming that a PID or a PI controller is used as the feedback control signal generator 112, the feedback signal component will be equal to the signal from the integrator component $p_i$.

In an embodiment the step S12 may immediately follow step S10 if it is determined that the conditions set in S10 are complied with. However, this may involve the risk of a sensible and audible transition of the clutch 20
from its locked operational mode to its slipping operational mode which causes a reduced driving comfort. In an alternative embodiment a transition between step S10 and step S12 may be provided by a stage wherein the feedback controller is enabled immediately but wherein the setpoint for the sliprate $n_{s,\text{ref}}$ is gradually increased from zero slip to the stable slipping operational mode.

Once it is determined at point in time $t_{l4}$ that the feedback control signal is stabilized, in step $S13$, a representative value $c_i$ is assessed for the control signal $p_c$. This may in practice be the output of the integrator component in the control signal generator $112$ as determined at point in time $t_{l4}$. Also a representative value $T_{iuc}^*$ is assessed for the temperature $T_{iu_c}$ of the clutch $20$, e.g. a representative value for the temperature $T_{0ii}$ of the hydraulic liquid used therein. Typically the transmission fluid temperature $T_{0ii}$ will rise during this operational mode of the clutch due to energy dissipation in the clutch. An average value of the transmission fluid temperature $T_{cT}$ during this first control mode of the controller may for example be the representative value. Alternatively, the representative value may be a value of the transmission fluid temperature $T_{cT}$ halfway the time window preceding $t_{l4}$ wherein stable operation was determined, or may be based on a measurement of the transmission fluid temperature at another point in time, which is corrected for changes due to energy dissipation. Still further a representative value $M_{iuc}^*$ is assessed for the torque transferred in the stable slipping operational mode maintained in the specified window of time preceding $t_{l4}$.

The representative values $c_i, T_{iuc}^*$ and $M_{iuc}^*$ are used in step $S14$ to determine updated settings for the emulation module $126$. To that end the update module $120$ may identify an entry in a lookup table maintained in the emulation module $126$ that corresponds to the representative values $T_{iuc}^*$ and $M_{iuc}^*$ for the clutch temperature and the transferred torque respectively and replace the value for that entry by the representative value
ci for the feedback control signal component. Alternatively the update module 120 may replace the old value in that entry by a value determined as a weighted mean of the old value and the representative value. It is noted that an entry in a lookup table maintained in the emulation module 126 corresponds to the representative values $T_{iuc}^*$ and $M_{iuc}^*$ if the entry has boundary values for the temperature and the transferred torque that contains these representative value. In still another embodiment wherein the value of the adaptation signal component $P_{adp}$ is calculated as parametric function of the value for the transferred torque $M_{iuc}$ and the value of the temperature $T_{iuc}$, the update module 120 may adapt the parameters of this function to bring the adaptation signal component $P_{adp}$ into correspondence with the representative value $ci$ for the feedback control signal.

In the embodiment shown, the update for the settings of the emulation module 126 is not immediately applied. Instead in step S15 at point in time t15, the clutch returns to its locked operational mode with its old settings. Instead the update is postponed until at a point in time t16 the clutch enters an open operational mode. At that point in time the new settings are applied in step S16. The change in the settings will be not noticeable by the driver.

It is noted that exemplary embodiments may be implemented in digital electronic circuitry, or in computer hardware, firmware, software, or in combinations of them. Whereas by way of example specific functions may be performed by respective dedicated functional elements, it is alternatively possible to perform various functions by a same element at different points in time. Example embodiments may be implemented using a computer program product, e.g., a computer program tangibly embodied in an information carrier, e.g., in a machine-readable medium for execution by, or to control the operation of, data processing apparatus, e.g., a programmable processor, a computer, or multiple computers. In an example embodiment,
the machine-readable medium may be a non-transitory machine- or computer-readable storage medium.
Claims

1. A control apparatus (100) for controlling a clutch (CL) in a transmission system, the clutch being controllable with a control signal \(P_{\text{set}}\) to selectively assume one of an open operational mode, a controlled slipping operational mode and a locked operational mode, the control apparatus including an open loop controller (OLC) with an emulation module (126) and an update module (120) to update the emulation module, the control apparatus further including a feedback controller (CLC) to provide a feedback control signal component \(P_c\) based on an observed response of the clutch,

   the control apparatus at least having a first and a second control mode; wherein in the first control mode the feedback controller is enabled to generate a feedback control signal that maintains the clutch in a stable, slipping operational mode according to predetermined specifications, in which first control mode the controller assesses a representative feedback signal value \(c_i\) of said feedback control signal as well as one or more respective representative state values for one or more clutch state signals; wherein the control apparatus uses the representative feedback signal value and the one or more respective representative state values to update the emulation module,

   wherein in the second control mode the feedback controller is disabled and wherein the open loop controller generates a control signal to maintain the clutch in the locked operational mode, the control signal having a value dependent on a emulation signal value of an emulation signal generated by the updated emulation module dependent on an actual value of said one or more clutch state signals.
2. The control apparatus according to claim 1, wherein the feedback controller comprises an integral action control component (112) and wherein the representative feedback signal value is determined with said integral action control component.

3. The control apparatus according to claim 1, wherein the emulation module (126) is updated in said first control mode to reduce a difference between a value of the emulation signal associated by the emulation module with said one or more respective representative state values and the characteristic feedback signal value.

4. The control apparatus according to claim 3, wherein said difference is partly reduced.

5. The control apparatus according to one of the previous claims, wherein the one or more clutch state signals include a temperature signal (T_{iuc}, T_{oil}) indicative for an operational temperature of the clutch and wherein the controller in its first control mode determines a representative temperature value of said temperature signal and wherein further the control apparatus uses the representative feedback signal value (ci) and the representative temperature value (T_{iuc}^{*}) to update the emulation module (126).

6. The control apparatus according to claim 5, wherein the clutch is a clutch (30) in a DNR assembly, and wherein the feedback controller is configured to maintain as the stable, slipping operational mode an operational mode wherein the clutch transmits an at least substantially constant torque at an at least substantially constant slip rate, wherein an output rotational speed of the clutch is equal to zero.
7. The control apparatus according to claim 5, wherein the one or more clutch state signals further include a torque signal \((M_{\text{uc}})\) indicative for a torque transferred by the clutch (20) and wherein the controller in its first control mode determines a representative torque value \((M_{\text{uc}}^*)\) of said torque signal; wherein the control apparatus uses the representative feedback signal value \((c_i)\), the representative temperature value \((T_{\text{uc}}^*)\) and the representative torque value \((M_{\text{uc}}^*)\) to update the emulation module (126).

8. The control apparatus according to claim 7, wherein the clutch \((\text{CL})\) is a lock-up clutch (20), and wherein the feedback controller is configured to maintain as the stable, slipping operational mode an operational mode wherein the lock-up clutch transmits an at least substantially constant torque at an at least substantially constant slip rate, the control apparatus being configured to assess in said stable, slipping operational mode the representative torque value \((M_{\text{uc}}^*)\) being indicative for the at least substantially constant torque.

9. The control apparatus according to claim 8, wherein the control apparatus is configured to enable the open loop controller to gradually change an operational mode of the clutch in its locked operational mode to a slipping operational mode and to subsequently enable the feedback controller to maintain the clutch in the stable, slipping operational mode.

10. A power train in a continuously variable transmission system including a torque converter / lock-up clutch (TC/LUC) (20), a drive-neutral-reverse clutch (DNR) (30) and a variator (40), the power train further including a control apparatus according to one of the claims 1 to 6 for controlling the DNR clutch (20), and/or a control apparatus according to one of the claims 1-5 and 7-9 for controlling the lock-up clutch (30).
11. A method for controlling a clutch in a transmission system, the clutch being controllable with a control signal to selectively assume one of an open operational mode, a controlled slipping operational mode and a locked operational mode, the method comprising:

- in a closed loop control mode generating a feedback control signal that maintains the clutch in a stable, slipping operational mode based on an observed response of the clutch;
- assessing a representative control signal value of said feedback control signal with which the clutch is maintained in said stable, slipping operational mode signal as well as one or more respective representative state values for one or more clutch state signals indicative for a state of the clutch;
- updating an emulation model indicative for estimated response characteristics of the clutch based on the assessed representative control signal value and the one or more respective representative state values;
- in an open loop control mode, using the updated emulation model to generate an open loop control signal as a function of respective actual values of the one or more clutch state signals to maintain the clutch in its locked operational mode.

12. The method according to claim 11, wherein an integral action is used in the closed loop control mode, and wherein the representative control signal value is determined with said integral action.

13. The method according to claim 11 or 12, wherein the clutch is a DNR clutch and wherein the feedback controller is configured to maintain as the stable, slipping operational mode an operational mode wherein the clutch transmits an at least substantially constant torque at an at least substantially constant slip rate, wherein an output rotational speed of the clutch is equal to zero, wherein the one or more clutch state signals include
a temperature signal indicative for an operational temperature of the clutch and wherein said assessing comprises assessing a representative temperature value of the temperature signal; wherein said updating comprises using the representative control signal value and the representative temperature value to update the emulation module and wherein the updated emulation model is used to generate an open loop control signal as a function of an actual value of the temperature signal to maintain the clutch in its locked operational mode.

14. The method according to claim 11 or 12, wherein the clutch is a lock-up clutch, and wherein the stable, slipping operational mode is an operational mode wherein the lock-up clutch transmits an at least substantially constant torque at an at least substantially constant slip rate, and wherein said assessing comprises assessing a representative temperature value of a temperature signal indicative for an operational temperature of the lockup clutch and further assessing a representative torque value being indicative for the at least substantially constant torque; wherein said updating comprises using the representative feedback signal value, the representative temperature value and the representative torque value to update the emulation module;

and wherein the updated emulation model is used to generate an open loop control signal as a function of an actual value of the temperature signal and of an actual value of the torque signal.

15. The method according to claim 11, further comprising an open loop control mode preceding the closed loop control mode to gradually change an operational mode of the clutch from its locked mode to a slipping operational mode and to subsequently enable feedback control component to maintain the stable, slipping operational mode.
16. The method according to claim 11, wherein the open loop control signal to maintain the clutch in the locked operational mode, depends on the assessed representative values in a delayed manner in that an adaptation of the emulation model is postponed until the clutch has assumed an open operational mode.
START

S0

Yes

S1

No

S2

Yes

S3

No

S4

Yes

S5

END

FIG. 4
**A. CLASSIFICATION OF SUBJECT MATTER**

**INV.** F16D48/06  F16H61/14

ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

F16D  F16H

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

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See patent family annex.

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Date of the actual completion of the international search: 28 March 2019

Date of mailing of the international search report: 03/04/2019

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