Modelling of a Prognostics Observer for Automated Manual Transmission

Sivakumar Ramalingam, Sanjeev Ramakant Pimpale, Srinivasa Prakash Regalla

Abstract

Currently gear actuation control of Automated Manual Transmission (AMT) does not receive the feedback on the actual condition of the gearbox hardware, particularly synchronizer which is critical for gear shift quality. This paper covers modelling of a Prognostics Observer for AMT system. The observer captures the real time position of the gear shift actuator, specifically during synchronization phase of the gear shift cycle. Based on the travel measured at the gear actuator end, synchroniser wear is estimated. Also, the synchronization time is continuously monitored and warning for re-calibration of the AMT system is provided when the synchronization time goes beyond the allowable limits. Condition monitoring provides the prognostic functionality for AMT system using ensures consistent gear shift quality, desired vehicle driveability and warning for repair and/or re-calibration. Also, systematic analysis of the monitored data provides an accurate diagnosis of a developing fault. Thus, with the advanced control systems in place for AMT, it is possible to develop a closed loop feedback based condition monitoring system for improved diagnostics and prognostics of AMT system.

Keywords: Automated Manual Transmission, AMT, Prognostics, Diagnostics, Observer, Condition Monitoring, Gear Shift Quality.

1 Introduction

Automated Manual Transmission (AMT) is an advanced "Shift by wire" technology which is integrated on a conventional manual transmission (MT). An AMT system consist of a dry clutch, a base gearbox (same as MT), and an embedded dedicated transmission control system that uses electronic sensors, processors, and actuators to actuate clutch & gear shifts. It operates similar to a manual transmission except that it does not require clutch actuation or gear shifting by the driver. No clutch pedal is present and the gear shift lever is replaced by a joystick (only forward or reverse gear is selected by the driver).

AMT is almost two decade old technology and developed countries have migrated to advanced technologies like DCT. Electronic controlled engine (required for meeting stringent emission norms – BS4 & above) is a pre-requisite of AMT system as well. Hence, latest emission legislation in India has made AMT commercially feasible. Functional block diagram of a typical AMT System is as shown in Fig. (1). A fully automatic (AT) transmission deploys prognostics by fusing a degradation model with the pre-lockup feature from measurement, under the extended Kalman filtering framework [1].

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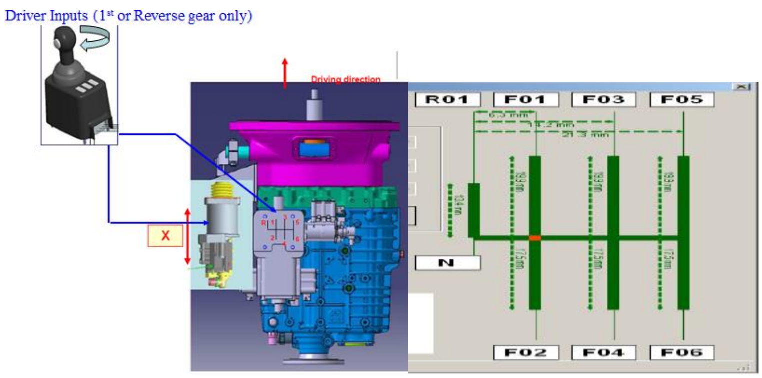

Figure 1: Typical configuration of the Automated Manual Transmission (clutch & gear shift systems) with inbuilt transmission controller housed in the joystick provided for driver. Source: Ashok Leyland Ltd presentation.

2 AMT Prognostics

Condition monitoring of systems for prognostics has gained popularity in recent decades due to potential savings in operating costs and higher reliability. The recent research and developments in diagnostics and prognostics of mechanical systems detailed by Andrew et al [2] include techniques like multiple sensor data fusion and condition-based maintenance (CBM) with emphasis on models, algorithms and technologies for data processing and maintenance decision-making It is an evolving domain with the advanced control technology but the methodology is yet to be matured for many applications.

Since the AMT system is automated and there is no driver intervention, closed loop condition monitoring of the gearbox would be helpful in effective diagnosis and prognostics of the system. Parker et al [3] specified generic fault detection, isolation, and estimation architecture using neural network-based fault pattern recognition in transmissions. Systematic analysis of the monitored data provides a diagnosis and prognosis of any developing fault.

Synchronisers work as cone brakes and they accelerate or brake the component to adjust the speed of shaft and gear. They are critical wearable part of the gearbox which impacts the gearshift quality as well as the reliability of the system. Hence, monitoring of the condition of the synchronisers will enable the prognostics system to set alarm for wear limits and provide alert if the condition exceeds specified accepted levels. Exploded view of the synchroniser assembly is as shown in Fig. (2).

Closed loop control of the automated manual transmission system integrated with condition based monitoring, for gear shift system needs to be modelled, simulated & calibrated for optimizing the shift controls of AMT electro-pneumatic gear shift system considering below listed targets:

- Minimize wear of parts in the transmission by periodical re-calibration
- Ensuring consistent shifting quality and comfort
- Optimizing shifting duration for improving launch / drivability

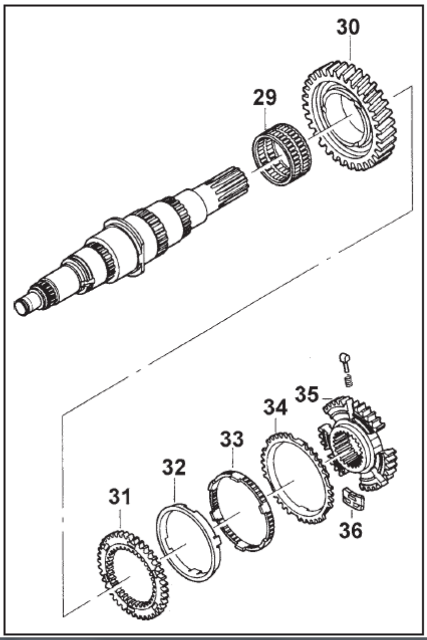

Figure 2: Exploded view of synchroniser assembly (cage 29; Gear 30; Clutch disc 31; Inner ring 32; Intermediate ring 33; Outer ring 34; synchroniser hub 35; coupling elements 36). Source: Ashok Leyland Ltd – Gearbox Service manual.

3 Prognostics Methodology

Prognostics methodology developed for AMT system is unique and provides simplified measurement and experimentally validated algorithm using lookup table incorporated in the prognostics module of the AMT controller.

The gear-changing process is defined by Lovas et al [4] under eight main operating phases using classical tribological, mechanics, and thermodynamics theories. But, it is possible to focus the measurement of synchronization time, force and shift actuator travel during the synchronization phase.

The main areas of current research in technical prognosis are: Metrics for Estimating Remaining Useful Life, Prognostics Methods Classification and Prediction Frameworks Krupa [5].

3.1 Synchronizer Wear

Synchronizer wear limit for replacement is specified in the service manual of any gearbox. Synchroniser wear which gets magnified by the overall linkage ratio at the AMT gear shift actuator is easily measured during the synchronisation phase. Once the pre-set alarm for wear limit is reached, warning message will be sent for checking and replacement of the corresponding worn out parts. System re-calibration has to be done to reset the actuator position and store the fresh learnt values of the Electrically Erasable Programmable Read-only Memory (EEPROM). Refer Fig. (3). for sample measurement data of the shift actuator travel.

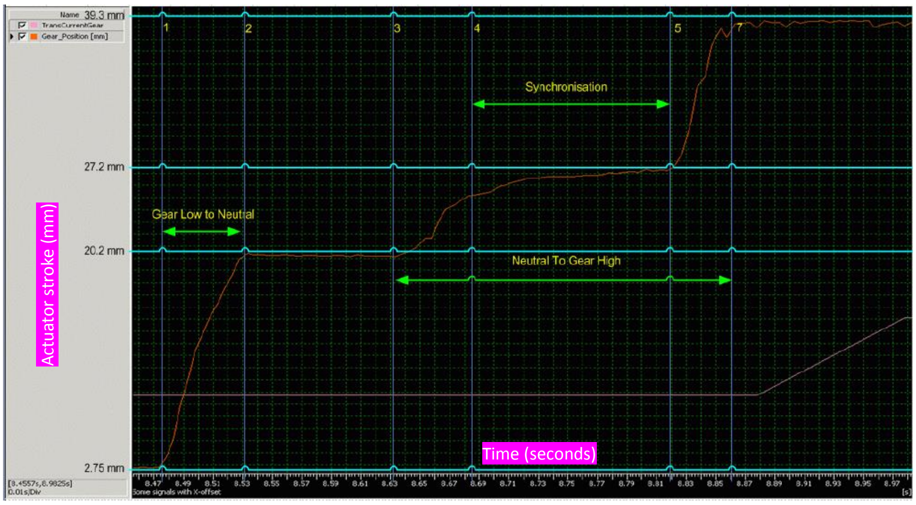

Figure 3: Sample measurement of gear actuator travel during synchronisation phase. Other phases are not considered for the analysis, being identical in nature.

3.2 Synchronization time

Synchronization forces corresponding to the specified synchronisation time limits are available from the gearbox testing. Synchronisation time needs to be monitored continuously for achieving consistency in gear shift quality and vehicle driveability. If the synchronisation time crosses the limits, gear synchronisation force is changed. Hence, warning is given to operator for checking and re-calibrating the system.

A dynamic simulation and analysis model of the gearbox synchronizer is considered because engagement of the synchronizer happen in a short time and it is hard to understand experimentally L. Yen-Chen and Y. Ching-Huan [6].

Sample test data showing the relationship between synchronisation force and synchronisation time during gear up/down shift is summarised in the Table 1.

Table 1: Force corresponding to limits of Synchronization time

	Synchronization force (N) for	
Gear shift	**0.3 second**	**0.6 second**
1 to 2	1557	864
2 to 3	1368	753
3 to 4	729	402
4 to 5	481	265
5 to 6	261	144
6 to 5	513	328
5 to 4	809	518
4 to 3	1456	932
3 to 2	1762	1127
2 to 1	3482	2217

4 Prognostics Observer

Luo et al [7] proposed a systems-oriented approach to prognostics requires that the failure detection and inspection-based methods be augmented with forecasting of parts degradation, mission criticality and decision support. Methodology for AMT prognostics observer development includes, Modelling → Simulation → Prognostics → Degradation monitoring → Prediction of remaining useful life → Warning/alert.

The observer is programmed for monitoring the synchronising time and gear shift actuator. The observer is integrated with the existing transmission controller of the AMT system. Block diagram of the AMT Prognostics Observer is shown in Fig. (4).

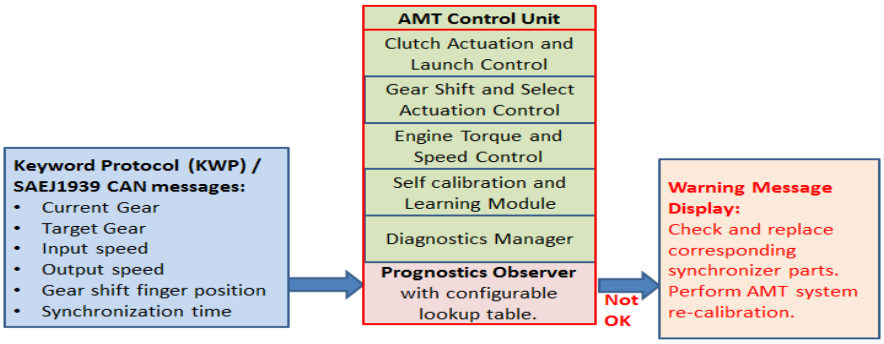

Figure 4: Block diagram of AMT prognostics observer integrated with the existing transmission controller.

4.1 Prognostics Observer

Langjord et al. [8] proposed an adaptive nonlinear observer for electro-pneumatic actuator which estimates piston velocity, chamber pressures and dynamic friction based on piston position measurement only. When an AMT system is installed on new gear box or repaired gear box, the system self-calibrates and stores the learnt values of all defined parameter in EEPROM of the controller. The prognostics observer is designed to monitor the current values, compare with the learnt values and assess the condition of the gearbox hardware using the lookup table as shown in Table 2.

Table 2: Lookup table for AMT prognostics integrated in the controller.

Gear Change	Learnt gear synchronization time (tl) seconds	Learnt shift finger position (dl) mm	Current gear synchronization time (tc) seconds	Current gear actuator position (dc) mm
1 to 2	tl1	dl1	tc1	dc1
2 to 3	tl2	dl2	tc2	dc2
3 to 4	tl3	dl3	tc3	dc3
4 to 5	tl4	dl4	tc4	dc4
5 to 6	tl5	dl5	tc5	dc5
6 to 5	tl6	dl6	tc6	dc6
5 t 4	tl7	dl7	tc7	dc7
4 to 3	tl8	dl8	tc8	dc8
3 to 2	tl9	dl9	tc9	dc9
2 to 1	tl10	dl10	tc10	dc10

4.2 Prognostics Algorithm

The closed-loop control strategy based on experimentally obtained applied force vs. motor position curve and related closed-loop motor position control is presented by Ivanovic et al [9]. A controller algorithm is proposed to compensate for the effect of clutch free-play variations due to clutch wear. The experimentally validated closed loop algorithm proposed for the AMT prognostics is explained with the help of a flow chart in Appendix A.1.

4.3 Prognostics Messages

The max wear limit for synchroniser is “x” mm (depends on design) and the prognostics alert/warning message alert is provided when it reaches 0.9x mm. The limit for synchronisation force is defined for typical synchronization time of 0.3 to 0.6 second (from experimental data). The real time prognostics warning messages from the observer for recalibration and/or servicing can be provided on board and/or off-board for remote diagnostics.

5 AMT Experimental Setup

Manual gearbox performance test rig was modified to suit AMT gearbox prognostic observer experimentation. Typical AMT gearbox test setup is shown in Fig. (5). .

Figure 5: AMT gearbox test rig with prognostic observer inbuilt controller.

6 Test Results Summary

Screenshot of the sample measurement of synchronisation time and gear actuator travel using CANAPE (development software tool from Vector Informatik used to calibrate algorithms) is summarised in Appendix A.2. This confirms that data acquisition during synchronisation phase is can be captured on real time and analysed by the prognostic observer for precisely monitoring the degradation.

7 Conclusions & Future wor

Prognostics Observer for AMT gearbox is integrated with the existing transmission controller, for real time monitoring of synchroniser wear (through gear actuator stroke) and synchronising time. Using algorithm and lookup table, condition of the synchroniser is assessed and warning is given at pre-set limit for checking and replacing the worn out parts. Also, synchronisation time limits are set to provide alert for re-calibration of the system to ensure consistent shift quality.

Normal wear due to usage to be established by testing and factored. The prognostics observer algorithm needs to be further optimized by modelling and simulation, using Simulink/Stateflow (Matlab software from Mathworks). Also, it is feasible to incorporate clutch system monitoring into the AMT prognostics observer which would be a complete prognostics system.

Acknowledgement

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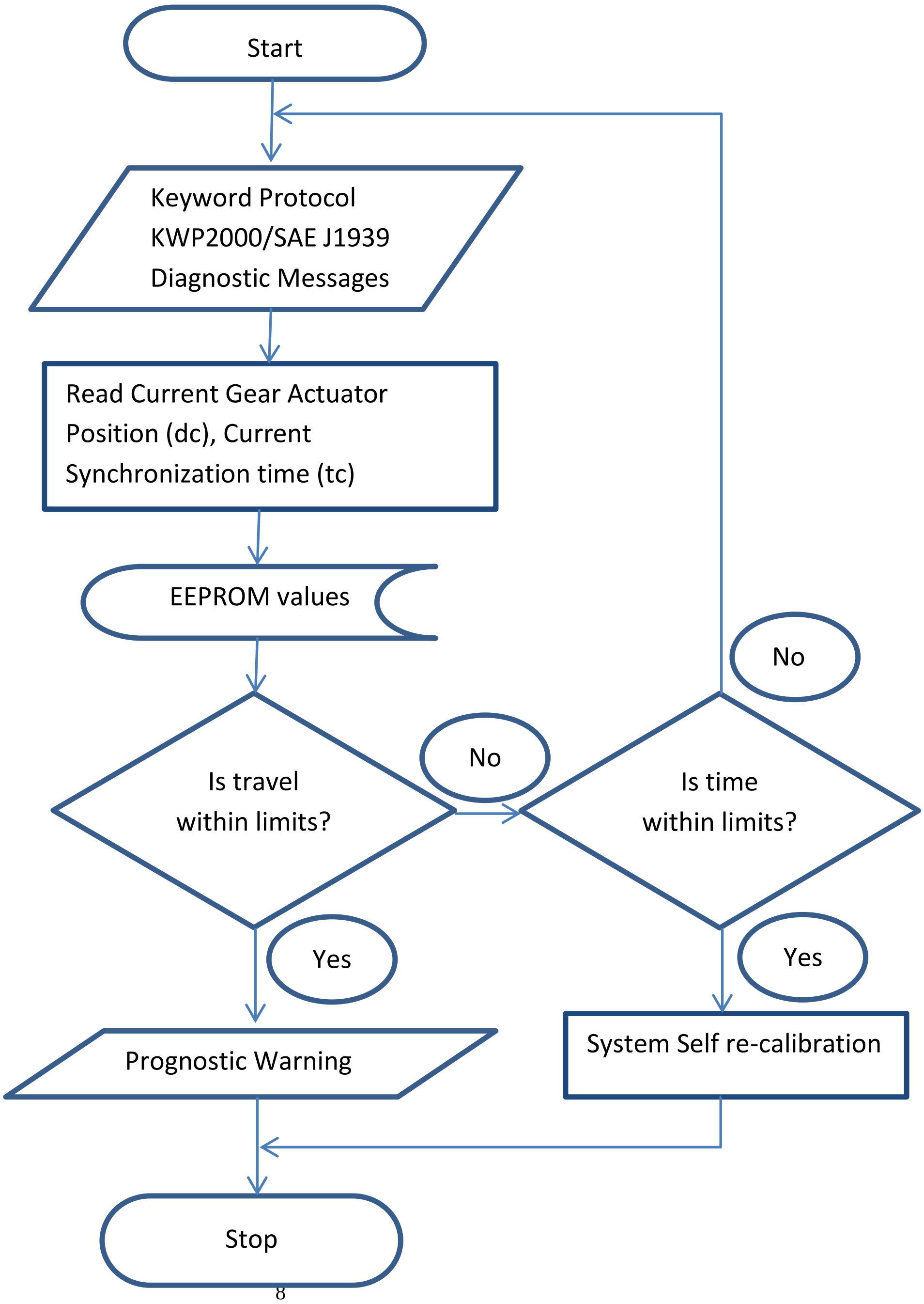
Appendix

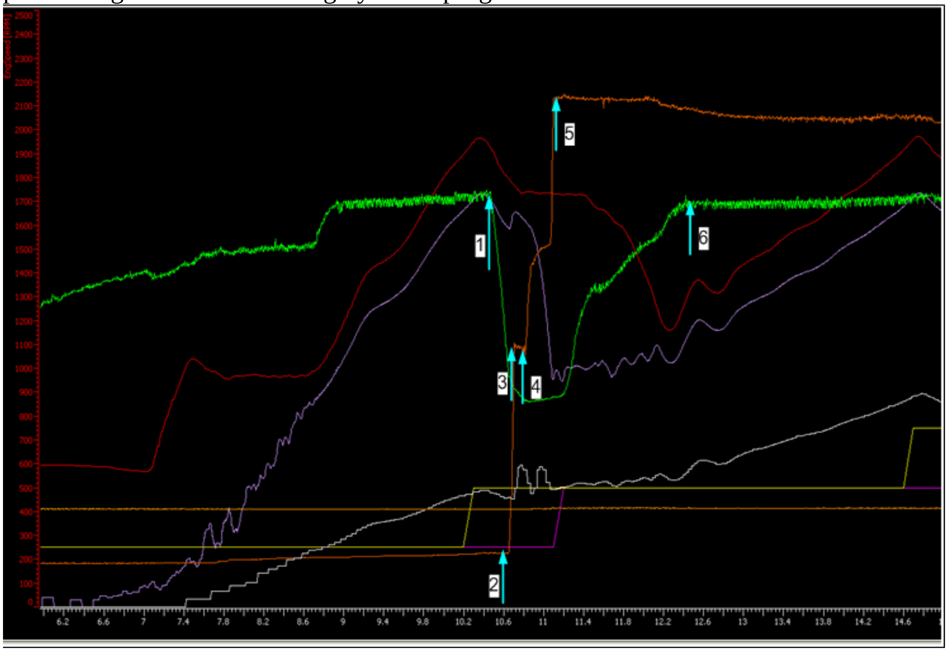
A.1 Flow chart for AMT Prognostics Algorithm

Below flow chart details the algorithm developed for AMT prognostics.



A.2 Synchronization time and actuator travel measurements

Sample real time measurement data measurement of clutch & gear shift sequence, for precise degradation monitoring by AMT prognostics observer.



Legend for above measurement data	
	Current Gear
	Selected Gear
	Input shaft speed (rpm)
	Gear Position
	Output shaft speed

Event description:

1 to 2 → Clutch disengagement
2 to 3 → Gear to neutral shift
3 to 4 → Selection movement
4 to 5 → Neutral to gear shift
2 to 5 → Gear to gear shift