SELECTED PROBLEMS IN DIAGNOSTIC TESTING OF AUTOMATIC TRANSMISSIONS (AT)

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Summary

The problems connected with the diagnostic testing of modern automatic transmissions (AT) have been presented. The applicable diagnostic methods have been reviewed and evaluated. The systems and components subject to accelerated wear and tear have been indicated. The reasons for AT damage have been analysed and the consequences of specific defects have been discussed. A test system of unique design, specially engineered and made for automatic transmission diagnostics based on signals obtained from the hydraulic AT control system, has been presented. Example results of diagnostic tests have been given and analysed.

Keywords: AT – automatic transmissions, AT diagnostics, hydraulic circuit, electrohydraulic control of automatic transmissions

1. Introduction

The modern automatic transmission (AT) is a complicated unit, which requires appropriate operation and specialized maintenance. The workshop practice also shows that automatic transmissions are subject to damage, especially when used in vehicles with engines of high power and torque capacity. Due to its high constructional complexity, the AT is a vehicle component for which diagnostics is very difficult.

The technical diagnostics is an organized set of methods and means for assessing the technical condition of an object, with the technical condition being defined, in terms of the quality and safety of operation of the object, by a vector of direct or indirect measures. The direct measures of the technical condition of a mechanical object, defined as object's condition features, include e.g. geometrical dimensions of mating

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parts, trajectories of working organs, or stress-strain state characteristics. The indirect measures of the technical condition, reflecting the current degree of wear and tear or the quality of functioning of the object, are referred to as "symptoms", i.e. measurable quantities corresponding to the features of the technical condition of the object. The "symptoms" are measures of diagnostic signals and they are determined by examining the working and accompanying processes related to the technical object under consideration. A symptom may be considered a diagnostic signal (parameter) of the technical condition if the following criteria are met [5, 18]:

- uniqueness, i.e. a requirement that each value of an object's condition feature should be related to an exactly one value of the output parameter;
- adequate width of the range of changes, i.e. a requirement that for a specific change in the object's condition feature, the corresponding change in the output parameter value should be sufficiently big;
- availability, i.e. a criterion describing the measurability of the signal.

A mistake that is frequently made during the AT repairing process is counteracting the effects of the system damage (by replacing the damaged components) rather than eliminating the reasons for the problem. Not all of the methods employed to date in the AT diagnostics make it possible to obtain usable test results, especially as regards the evaluation of the technical condition of the hydraulic control system.

Such a situation usually results in a similar AT component failure occurring again after a short period of system operation following the repair carried out. This article shows the basic AT diagnostics methods and presents a unique method and test system for evaluating the technical condition of an automatic transmission based on signals obtained from the hydraulic AT control system. The diagnostics is based on measurements of the main fluid supply pressure p_g in the hydraulic system and the pressure p_k in the torque converter during a field test.

2. Methods of diagnostic testing of automatic transmissions

The automatic transmission system consists of several subassemblies, with each of the latter having a very complicated structure. A success in the diagnostic process depends to a significant extent on the diagnostic methods adopted. The diagnostic information about the current technical condition of the AT system is carried by a signal in the form of fluid pressure in the hydraulic control system. The known basic methods of diagnostic examination of an automatic transmission unit usually include [1–4, 10, 12–15, 17]:

- visual inspection for automatic transmission fluid (ATF) leaks from the AT unit;
- assessment of the type and degree of contamination of the automatic transmission fluid;
- checking of the ATF level in the transmission unit;
- computerized stationary diagnostics;
- measurements and assessment of the ATF pressure at diagnostic take-off points in

the hydraulic system in the conditions as defined in the instruction manual;

- measurements and assessment of the time lag ("Time Lag Test") between selected AT operation programs;
- "Stall Test" (a kind of overload test);
- field (road) tests, during which the general system functioning is checked.

When carrying out the diagnostic process, one should keep in mind the interferences that might cause errors in the diagnosis. In the case of AT diagnostics, the diagnosis errors may be chiefly caused by defects in the engine and its auxiliaries. The existing diagnostic methods are burdened with many limitations.

The visual inspection of ATF leaks makes it possible to draw preliminary conclusions about the technical condition of the AT unit, but in a subjective way only. According to the basic design requirements and technical specifications that must be met by a vehicle subjected to a periodic technical inspection, any external ATF leaks from the AT unit shall not be accepted and the leaking automatic transmission must be repaired.

The assessment of the type and degree of contamination of the automatic transmission fluid covers in practice the following:

- testing of water (coolant component) content in the ATF by inertial separation, with the use of a workshop test device (the water content should not exceed 0.05 % by volume) [13];
- testing of ethylene glycol (coolant component) content in the ATF by a chemical method;
- visual assessment of the contamination of centrifugal, gravity, or magnetic filters in the ATF tank with metallic (ferrous) wear debris;
- visual assessment of the degree of contamination of the filter barrier in the hydraulic control system with products of wear of AT components;
- determining of the ATF contamination degree by means of a disposable tester (with filtering several ATF drops through special filter paper and comparing the paper with a reference standard).

The ATF level in the transmission unit, varying during the transmission operation period, may be a valuable source of practical diagnostic information. In case of incorrect ATF level, the fluid should be added as required before starting the diagnostic tests. Significant ATF losses, if no fluid leaks from the transmission unit have been detected, may indicate excessive slippage of wet multidisc clutches and brakes, which may cause the fluid to burn away. Conversely, rising ATF level may be caused by coolant penetration into the hydraulic system of the automatic transmission. The quantity and type of the products of wear of AT components as well as the size of particles contaminating the hydraulic fluid are diagnostic signals informing about the technical condition of the hydraulic control system [16].

The computerized stationary diagnostics is very helpful in the process of diagnostic testing of modern automatic transmissions; however, it has some limitations, too. The effectiveness of the diagnostic process, i.e. the quality and accuracy of the diagnosis given, largely depends on the degree of complication of individual subsystems in the automatic transmission under test. Better diagnostic information may be obtained if the control system is provided with additional measuring sensors. Thanks to measurements of differences in angular speeds of rotating transmission components, the system may generate diagnostic information about excessive slippage of transmission clutches. Another diagnostic signal may be the ATF temperature in the hydraulic system of the transmission unit. Excessive working temperature of the ATF shows that the transmission under test is out of order although the actual defect cannot be thus exactly indicated. In addition to this, modern AT controllers are provided with diagnostic systems, which make it possible to monitor some electrical parameters, e.g. resistance of the coil winding of a solenoid control valve, thanks to which the reason for the faulty transmission operation may be precisely identified with the use of an automotive diagnostic scanner.

The ATF pressure values determined at diagnostic take-off points in the hydraulic system during transmission operation make it possible to draw conclusions about the general technical condition of the AT unit under test, in particular about the technical condition of its hydraulic system components. The quality of the diagnosis given largely depends on the number of the diagnostic take-off points. The measuring of ATF pressure in the specific hydraulic system section that is involved in the implementation of a specific gear makes it possible to identify the defect more accurately. The value of the ATF pressure in the hydraulic system in a specific system operation state depends on the degree of wear of the hydraulic pump, internal leaks in system components, and degree of contamination of the filter screen in the hydraulic system. A drop in the ATF pressure value in certain conditions of vehicle motion entails a proportional reduction in the force of pressure applied by the actuator piston to the multidisc clutch or brake that implements a specific gear, which may result in excessive slippage. The excessive slippage, in turn, leads to "burning", "flaking", or even welding of the friction material of clutch facing. With increasing slippage, the ATF temperature rises in the friction area and causes excessive fluid oxidation. Moreover, big differences between the velocities of mating friction surfaces intensify the ATF shearing process. Changes in the physicochemical ATF properties as well as fluid contamination may cause malfunctions of the hydraulic system. The malfunctions result from excessive internal leaks (insufficient ATF pressure in specific conditions of system operation). On the other hand, contaminant particles with dimensions close to the values of clearance in high-precision pairs of the electrohydraulic control system cause blocking of distribution valve spools and scratching of sleeve surfaces. All this may result in malfunction and accelerated wear and tear of hydraulic distributor vales.

The "Stall Test" (a kind of overload test) makes it possible, first of all, to verify the technical condition of the hydrokinetic torque converter. This test is carried out with vehicle engine running, service brake fully applied, and drive mode selector lever set to "D".

At this test, the actual maximum engine speed is read from the tachometer on the vehicle instrument panel and compared with the specifications provided in the vehicle service manual. If the actual maximum engine speed exceeds the value specified in the manual (e.g. 2 100±150 rpm as specified for the vehicle actually used for the tests, see Section 4), such a finding indicates excessive wear (slippage) of the automatic transmission; conversely, if the actual engine speed is too low then the vehicle engine does not function properly (its maximum power output is unsatisfactory) [10]. Such a test should not be carried out for a period exceeding a few seconds because of rapid growth in the ATF fluid temperature in such test conditions. In the case that the automatic transmission under examination is worn to a significant extent, the stall test may result in total destruction of the transmission unit, i.e. damage to a large number of transmission components and increased cost of repair, should the repair have to be undertaken.

The time lag test (i.e. measurement of the time of switching to another AT operation program) indirectly shows the technical condition of parts of the hydraulic system. The shifting of the drive mode selector lever to another position results in supplying the ATF pressure to another section of the hydraulic system. As an example, the time lag at actual changing of the system operation mode when the drive mode selector lever is shifted from "*Neutral*" to "*Drive*" and from "*Neutral*" to "*Reverse*" should not exceed 1.2 s and 1.5 s, respectively, for an automatic transmission in full running order. The time lag exceeding the value specified in the service manual indicates excessive wear of the hydraulic system of the AT under test [15].

The field (road) test is a way to verify the AT functioning during normal operation. During such a test, imperfections of smoothness of the gear shifting process (jerks), noise, and presence of perceptible excessive slippage can be assessed. To carry out tests of this type, a diagnostic engineer must have very good experience in this field; in spite of that, this method gives only a subjective view of the technical condition of the object of diagnostic examination.

3. Defects of AT components and systems

The following AT components are subject to intensive wear and tear [7]:

- hydrokinetic torque converter;
- hydraulic pump;
- hydraulic system seals;
- friction pairs (multidisc clutches and brakes);
- planetary gearsets and gear bearing systems;
- electrohydraulic controller.

In automatic transmissions, the components that are particularly often subject to damage are friction pairs (wet multidisc clutches and brakes). The most important factor that causes them to fail is thermal overload, which may also result from a drop in ATF viscosity. Other reasons for the thermal overload include [6]:

- too rapid growth in the friction force between the working surfaces of the clutch and brake involved (jerks during gearshift operations);

- too slow growth in the friction force between the working surfaces of the clutch and brake involved (excessive slippage during gearshift operations);
- insufficient force exerted by the hydraulic actuator, resulting in insufficient value of the friction force between the working surfaces of the clutch and brake involved (excessive slippage);
- ATF temperature exceeding the acceptable fluid temperature limit (too slow heat removal from the friction pair).

The course of changes in the friction forces developing between working surfaces of multidisc brakes and clutches may be disturbed by irregularities in the working processes that occur in the hydraulic AT control system. Friction pair defects are caused, as a rule, by disturbances in the processes taking place in the hydraulic system. The time history of the friction force largely depends on the curve representing the growth in the actuator piston force and on the final value of this force. The courses of the working processes that occur in the hydraulic system of an automatic transmission may be adversely affected by:

- malfunctions in the hydraulic distributor valves;
- internal leaks in the system;
- inadequate technical condition of the hydraulic power supply source.

The correct functioning of hydraulic distributor valves strongly depends on the conditions of operation of the high-precision hydraulic pairs incorporated in the valves, especially the degree and characteristics of contamination of the automatic transmission fluid. The internal leak-tightness of the system depends on the degree of wear and degradation

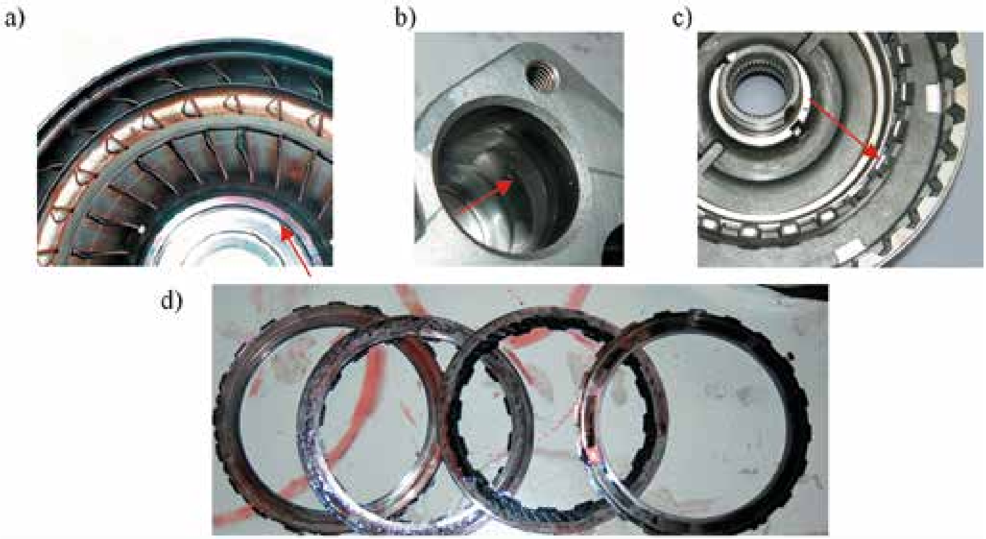

Fig. 1. Damaged AT components: a) pump impeller [14]; b) cylinder sleeve in the electro-hydraulic controller block; c) clutch cage; d) clutch discs and steel counter-plates [7]

of all the seals operating under pressure and the ATF viscosity. Another factor that has a very strong impact on the course of the working processes that take place in the hydraulic system of the AT unit is the technical condition of the pump, i.e. maintaining of the required safety margin in the ATF supply and pump capability of generating an adequate ATF pressure.

Examples of damage to AT components have been presented in Fig. 1.

Fig. 1a shows damage to converter pump impeller vanes. Most likely, the damage was caused by the impact of metal filings contaminating the ATF on the vanes [14]. Fig. 1b shows worn cylindrical surface of a valve sleeve in the electrohydraulic controller block, mating with the piston of a hydraulic damper. Fig. 1c shows mechanical damage to the clutch cage joint slots due to engaging two gears at the same time. Fig. 1d shows damaged friction elements of a multidisc clutch. The damage was caused to friction linings, which are made by pressing and gluing of cellulose layers and aramid fibre (the thickness of a single friction lining element is about 0.5 mm) onto a steel sheet carrier disc (about 0.8 mm thick) [11].

4. Examination of the diagnostic signals of the hydraulic control system

Due to functional and structural similarities between the hydraulic systems of automatic transmissions of motor vehicles and the hydraulic systems of heavy machinery, the scopes and methods of diagnostic testing are also similar in both cases. Therefore, the diagnostic methods and equipment used for the examination of hydraulic systems of heavy machinery can be adapted for the purposes of diagnostics of such systems in motor vehicles [13].

The road tests of the AT unit were carried out with the use of a diagnostic system of unique design (Fig. 2), consisting of pressure transducers, ATF temperature sensor, signal lines, signal recorder, and portable computer of the PC class. During the tests, the values of ATF pressures at diagnostic take-off points D_1 and D_2 in the hydraulic system of the automatic transmission were recorded with the use of piezoelectric transducers. The engine speed ns was measured with the use of a tachometric pick-up placed at point D_{ns}. The ATF temperature sensor was installed in the ATF drain plug at diagnostic point D_T. The analog signals were collected from individual transducers and fed to the recorder (2) via signal lines (4). The system interface was located in the portable computer, which was connected with the recorder via a cable of the RS232 class with an USB adapter (5).

The diagnostic tests were carried out on the hydraulic control system (Fig. 4) of the ZF4HP-24 automatic transmission unit (Fig. 3) of the Land Rover RR P38A car model manufactured in 1995–2002.

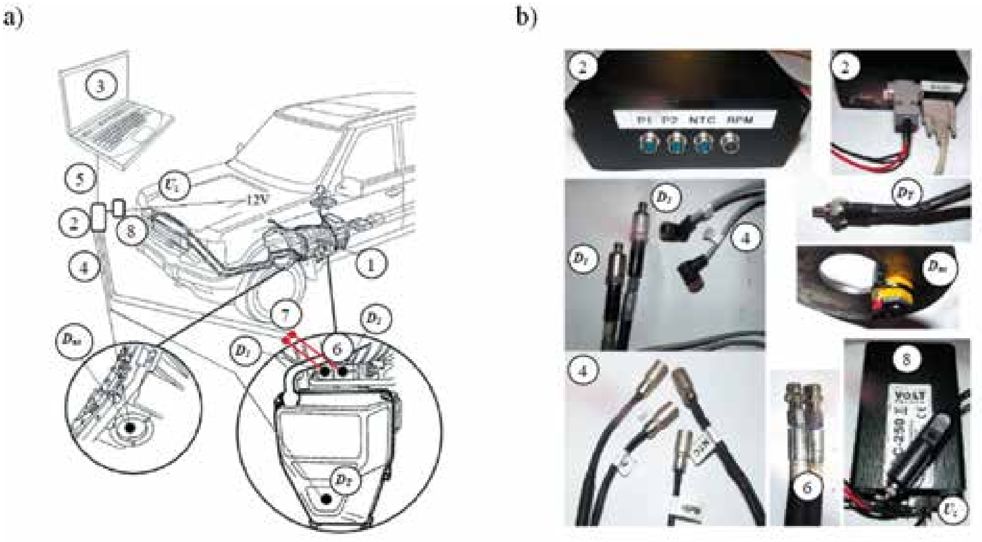

**Fig. 2. Diagnostic system: a) connection diagram; b) view of system components;
1 – automatic transmission ZF4HP-24; 2 – signal recorder; 3 – portable computer of the PC class; 4 – signal lines; 5 – cable to connect the signal recorder with the computer; 6 – hydraulic damping lines; 7 – pressure transducers; 8 – 12/24 V converter; D_1 – diagnostic take-off point for recording the main ATF supply pressure p_g; D_2 – diagnostic take-off point for recording the ATF pressure p_k in the torque converter; D_T – ATF temperature T measuring point; D_{ns} – engine speed n_s recording point; U_z – system to supply the recorder with 12/24 V power from the lighter socket**

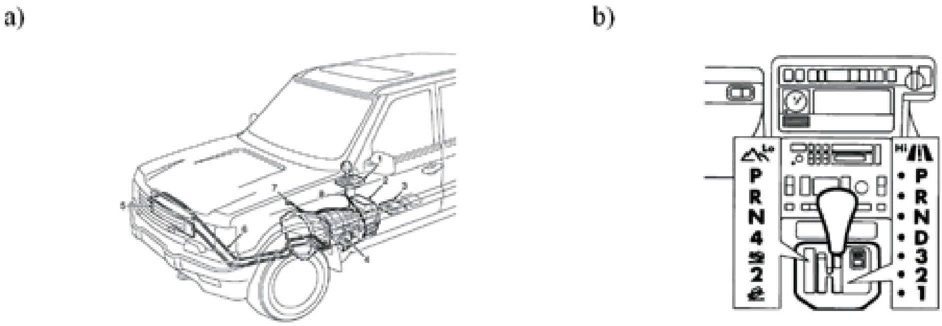

**Fig. 3. The ZF4HP-24 automatic transmission system: a) automatic transmission component layout;
b) drive mode selector lever assembly with an "H gate" mechanism;
1 – drive mode selector lever assembly; 2 – automatic transmission (AT) ZF4HP-24;
3 – electronic AT (EAT) controller; 4 – drive mode selector position switch;
5 – ATF cooler; 6 – ATF lines; 7 – AT breather tube; 8 – drive mode selector cable [12]**

The main component of the hydraulic control system of the automatic transmission is an electrohydraulic controller, which is composed of several dozen spool distribution valves incorporated in a body made of an aluminium alloy. The spools are operated by ATF pressure and flow. Depending on their function, the spools move to predefined extreme or intermediate positions. Individual distributor valve ports are appropriately connected by fluid passages (fluid flow routes) marked in the diagram (Fig. 4). Moreover, the electrohydraulic controller also includes electromagnetic (solenoid) valves (27 in Fig. 4). The actuating elements in the system are hydraulic actuators attached to specific wet multidisc clutches and brakes, denoted in Fig. 4 by letters A, B, C, C', D, E, and F. The fluid pressure is provided by an internal gear pump.

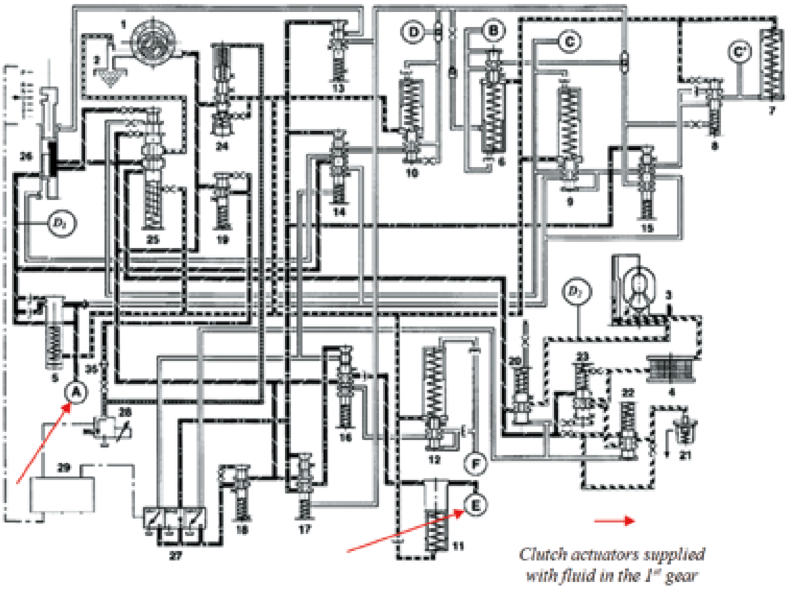

Fig. 4. Schematic diagram of the hydraulic control system of the ZF4HP-24 automatic transmission, with the electrohydraulic controller components and ATF flow routes shown for the selector lever set to "D" and the 1st gear being implemented: 1 – hydraulic pump; 2 – hydraulic filter; 3 – torque converter; 4 – ATF cooler. Electrohydraulic controller: 5 – hydraulic damper of clutch "A"; 6 – spool distributor valve of clutch "B" with a hydraulic damper; 7 – hydraulic damper of brake "C'"; 8 – spool distributor valve of brake "C"; 9 – spool distributor valve of brake "C" with a hydraulic damper; 10 – spool distributor valve of brake "D" with a hydraulic damper; 11 – hydraulic damper of clutch "E"; 12 – spool distributor valve of brake "F" with a hydraulic damper; 13 – spool distributor valve of the reverse gear; 14, 15, and 16 – spool distributor valves of gear changes 1↔2, 2↔3, and 3↔4, respectively; 17 – spool distributor valve of the "*kick-down*" function; 18 and 19 – the first (1st) and second (2nd) spool-type pressure distributor valves, respectively; 20 – spool distributor valve of the torque converter; 21 – overflow valve of the lubrication system; 22 – spool distributor valve controlling the lubrication pressure; 23 – lock-up clutch control valve; 24 – pressure-modulating valve; 25 – spool distributor valve distributing the main pressure; 26 – spool distribution valve of the drive mode selection system, mechanically operated; 27 – set of on-off solenoid valves MV1/MV2/MV3; 28 – proportional solenoid valve MV4; 29 – electronic AT (EAT) controller; D_1 – diagnostic take-off point for measurements of the main ATF supply pressure p_g; D_2 – diagnostic take-off point for measurements of the ATF pressure p_k in the torque converter

The diagnostic examination consisted of road tests carried out in accordance with the following procedures specially developed for this purpose:

- minimum vehicle acceleration test;
- maximum vehicle acceleration test.

At the minimum vehicle acceleration test procedure, the vehicle speed is raised from zero through all the possible gears being implemented in succession, with maintaining the engine speed n_s within a range of not more than 2 500 rpm at every gear ratio. The main quantities measured at the test are the main pressure p_g in the hydraulic system and the pressure p_k in the torque converter, recorded during a period of t_d during the road test (t_d – time stretch selected from the whole road test to analyse the signal). Moreover, the engine speed (actually the hydraulic pump rotor speed $n_{s(p)}$) is also recorded and the gearshift time $t_{i \to i+1}$ is evaluated on the grounds of the course of changes in the engine speed $n_{s(p)} = f(t_d)$ during the test.

The time histories of fluid pressure in the hydraulic system of the automatic transmission, recorded during the minimum vehicle acceleration test, have been presented in Fig. 5. The values of the main ATF pressure p_g exceeded those of the fluid pressure p_k in the torque converter. A rapid growth in both the main fluid pressure and the pressure in the converter can be seen at the beginning of vehicle acceleration, which is related to a steep increase in the AT load. The main pressure reached a maximum value of p_g = 787 kPa; then, its value dropped a while before the gear was shifted from first (1st) to second (2nd). The maximum values of this pressure, reached when the vehicle was driven in the second (2nd), third (3rd) and fourth (4th) gear, were p_g = 675 kPa, p_g = 736 kPa, and p_g = 681 kPa, respectively. An adequate value of the main pressure p_g in a specific section of the hydraulic actuator is necessary for the actuator piston to press its wet multidisc clutch or brake with an appropriate force. An insufficient value of this force will cause excessive slippage on the friction discs and, in consequence, overheating of, and finally, damage to, the friction linings (an example can be seen in Fig. 1d). On the other hand, an excessive value of this force will result in insufficient slippage in the initial phase of the engaging process, which may bring about mechanical damage to transmission parts (e.g. separation of friction material, breaking of clutch cages, etc.). Too low a value of the ATF pressure in the hydraulic control system chiefly results from wear and tear or ageing of sealing elements; excessive fluid pressure values are caused by malfunctioning of control elements (valve damage, seizing or contamination). The maximum value of the main ATF pressure p_g indicates that in specific AT operation conditions, the transmission was loaded to a maximum when the maximum pressure was reached. The value of the ATF pressure p_k in the torque converter informs about the converter load state (the higher the pressure value is, the greater torque is transmitted from the converter pump to the turbine). The diagnostic usability of this signal is, however, different: a sudden drop in the pressure value from about 500 or 600 kPa to zero means engagement of the lock-up friction clutch in the torque converter. In terms of system diagnostics, it is important to know whether and in which gear the lock-up clutch gets engaged. Moreover, the checking of the hydraulic control system part responsible for engaging the lock-up clutch consists in verifying whether any incorrect or uncontrolled disengagement of the lock-up clutch takes place during normal vehicle drive (in the graph, this would be visualized by return of the ATF pressure value to its working level corresponding to torque converter operation). The time history of the ATF pressure p_k in the torque converter is sufficient for assessment of the lock-up clutch engaging and disengaging processes. For the functioning of the hydraulic AT control system to be fully assessed within the scope of the technical condition of the torque converter, the limit values of the p_k pressure must be known, but such data cannot be found in the available literature.

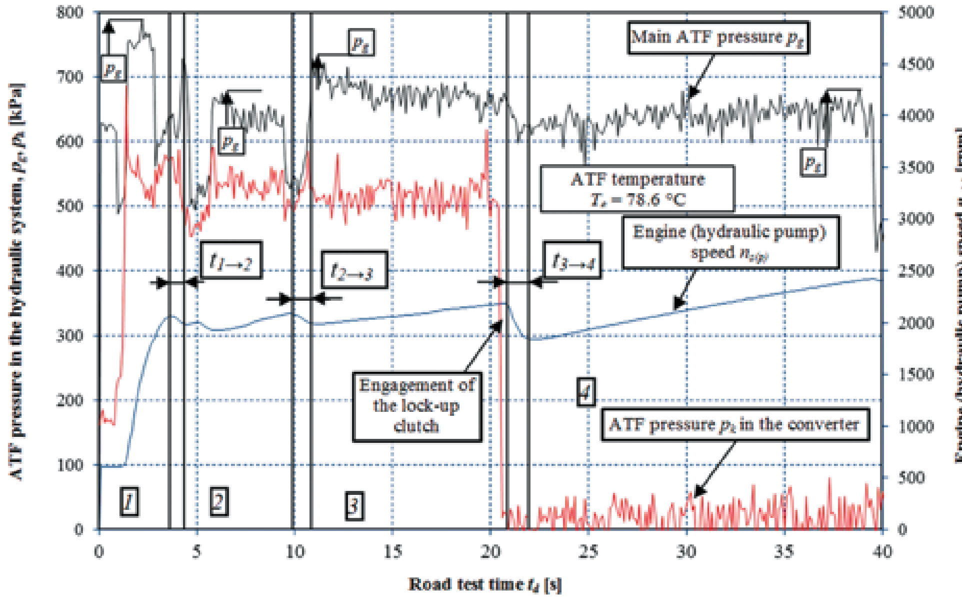

Fig. 5. Values of ATF pressures p_g and p_k in the hydraulic system and of engine (hydraulic pump) speed $n_{s(p)}$ vs. time t_d of the minimum vehicle acceleration test (with minimum displacement of the accelerator pedal), with the gearshift time $t_{i\to i+1}$ being also shown in the graph

An important diagnostic signal may be the gearshift time. The gearshift time $t_{i\to i+1}$ cannot be determined from the value of the main fluid pressure in the hydraulic system of an automatic transmission where the fluid pressure in individual sections of the actuating elements (actuators) cannot be recorded for technical reasons, as it was in the case of the transmission under test. Instead, however, the gearshift time $t_{i\to i+1}$ can be determined from a time history of the engine speed $n_{s(p)}$ recorded during the test, providing that adequately high sampling frequency (at least 10 Hz) is maintained. Results of measuring the gearshift time (Fig. 6) have shown that the gearshift time $t_{i\to i+1}$ is considerably affected by vehicle motion conditions. At the maximum vehicle acceleration test, the time of filling the actuating elements (actuators) is definitely shorter and the gearshift process is less comfortable, i.e. it is more strongly felt by vehicle occupants. The diagnostic signal in the form of gearshift time recorded in precisely defined AT operation conditions (e.g. at the maximum vehicle acceleration test) may provide information about the technical condition of the lining of friction discs of a wet multidisc clutch or brake. However, a requirement must be simultaneously met that the main pressure value must be within the acceptable limits and the actuator piston must exert a force of pressure of an appropriate value, being in conformity with the basic design requirements. A gearshift time exceeding its nominal value would indicate excessive clutch or brake slippage, which would be connected with insufficient value of the friction force developing in the friction pair in spite of adequate pressure force being exerted by the actuator piston. Such a situation may be caused e.g. by the fact that the surface layer of the friction lining has been partly burnt and the structure of the surface layer of the steel counter-plates has changed; in result of this, local over-hardened spots ("hot spots") may appear, which would reduce the coefficient of friction at the interface between the friction lining and the steel counter-plate. The available literature does not offer useful precise information on the acceptable values of the diagnostic signal in the form of gearshift time in specific conditions of operation of the automatic transmission. However, some skimpy information can be found about measurements of the gearshift time and the possible use of such a signal in the diagnostics of automatic transmissions.

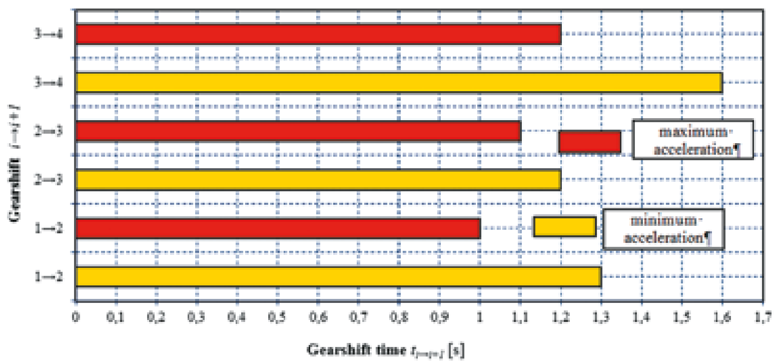

Fig. 6. Values of the gearshift time $t_{i\to i+1}$ during the minimum and maximum vehicle acceleration tests

The maximum vehicle acceleration test procedure makes it possible to check whether the automatic transmission will function correctly at maximum loads that might occur during normal operation and what values are reached by the diagnostic signals in such conditions. The maximum vehicle acceleration test is to be, in a way, a reflection of the stall test. However, such a test procedure does not lead to ATF overheating and does not introduce unnatural (other than occurring during normal operation) loads of the automatic transmission under test.

Results of recording the values of ATF pressures p_g and p_k in the hydraulic system and of engine (hydraulic pump) speed $n_{s(p)}$ vs. time t_d of the maximum vehicle acceleration test have been presented in Fig. 7. The value of the main ATF pressure depends on the values of engine crankshaft (hydraulic pump rotor) speed, transmission load, controlled setting of the pressure-regulating solenoid valve (MV4), and implementation of a specific gear, i.e. controlled combination of settings of on-off valves MV1 and MV2.

The maximum main pressure values p_g reached when the first (1st), second (2nd), third (3rd) and fourth (4th) gear were implemented during this test were p_g = 835 kPa, p_g = 700 kPa, p_g = 717 kPa, and p_g = 763 kPa, respectively. For a diagnosis on the automatic transmission to be given, the limit values of the main pressure pg in individual gears for the specific AT model must be known for comparisons with the actual test results. The conditions and program of both the minimum and maximum vehicle acceleration tests have been specially developed by the authors of this article. One of the objectives of further research carried out by the authors on the diagnostics of hydraulic AT control systems is the preparation of a method of determining the limit values of the main ATF pressure p_g in individual gears. The usability of the measured value of the ATF pressure p_k in the torque converter as a diagnostic signal is identical as it is in the case of the minimum vehicle acceleration test, i.e. this signal provides information about the functioning of the lock-up clutch. This information can be obtained without the acceptable limits of the ATF pressure in the torque converter being known.

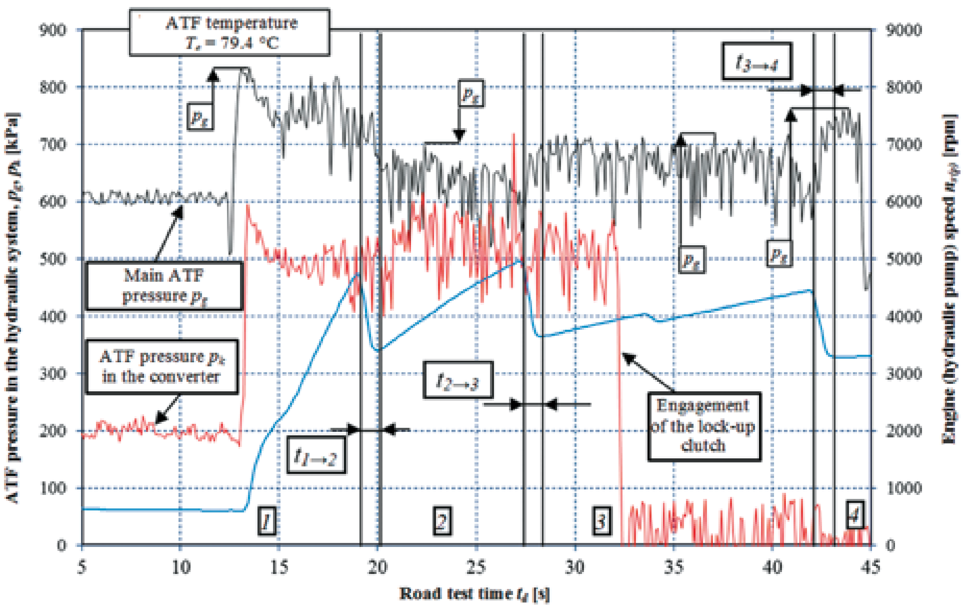

Fig. 7. Values of ATF pressures p_g and p_k in the hydraulic system and of engine (hydraulic pump) speed $n_{s(p)}$ vs. time t_d of the maximum vehicle acceleration test (with maximum displacement of the accelerator pedal), with the gearshift time $t_{i\to i+1}$ being also shown in the graph

At a test carried out with the "*kick-down*" function being used (i.e. with a sudden change to a lower gear), the vehicle was accelerated until the last gear was engaged and the engine speed was kept constant and not exceeding 2 500 rpm and then the accelerator pedal was fully depressed until the gear was changed down, which resulted in a sudden increase in the engine speed n_s to the acceptable limit (red zone on the tachometer scale).

Based on this test, the gear-down change time $t_{4\to 2KD}$ and the total slippage time $t_{4\to 2P}$ during the test were determined (Fig. 8). The diagnostic test enables unequivocal verification of the "*kick-down*" function, with the diagnostic signals being the time $t_{4\to 2KD}$ of shifting gears from the fourth (4th) to the second (2nd) and the total slippage time $t_{4\to 2P}$ being measured for the period during which this AT function was performed.

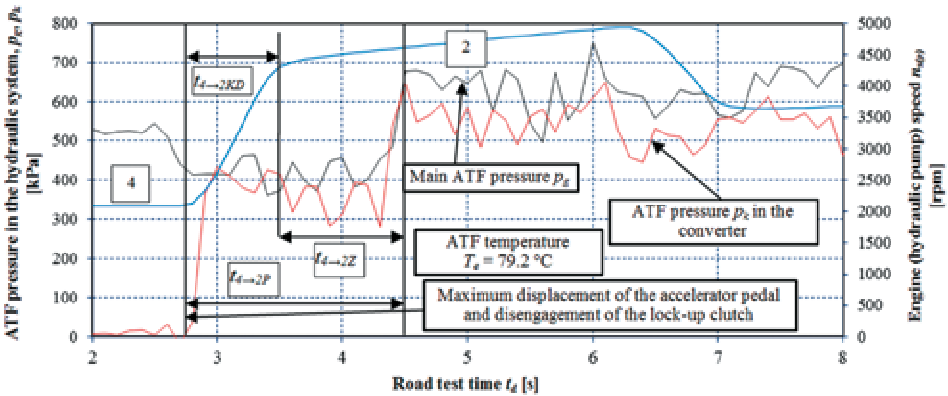

Fig. 8. Values of ATF pressures p_g and p_k in the hydraulic system and of engine (hydraulic pump) speed $n_{s(p)}$ vs. time t_d of the test with the "*kick-down*" function being used (when the accelerator pedal is suddenly fully depressed), with the gear-down change time $t_{4\to 2KD}$, total slippage time $t_{4\to 2P}$, and time lag $t_{4\to 2Z}$ being also shown in the graph

When the "*kick-down*" function is actuated (at the instant of the accelerator pedal being fully depressed), the electrohydraulic controller must disengage the lock-up clutch in the torque converter for the function to be correctly performed (otherwise the clutch could be destroyed), in result of which the p_k pressure will suddenly rise from zero to the level appropriate for the specific transmission operation conditions at the instant when the accelerator pedal is fully depressed (Fig. 8); this is a correct response of the system. When the electronic AT (EAT) controller generates a signal for the MV valve solenoid (to close valve MV3 and to open valves MV1 and MV2), which will change the position of the electrohydraulic valve spool and cause the transmission gear to be changed from fourth (4th) to second (2nd), the clutch slippage phase will be continued for a while because of the increasing actuator supply pressure being temporarily below the final value required for the implementation of the specific gear; this corresponds to the time lag $t_{4\to 2Z}$. Too long a time ($t_{4\to 2Z}$) of this slippage phase may result in damage to the friction pairs involved because of local overheating of friction linings of the wet clutches. The total slippage time $t_{4\to 2P}$ consists of the time of changing gears from fourth (4th) to second (2nd), i.e. $t_{4\to 2KD}$, and the time lag necessary for the main pressure value p_g to reach the level required for shifting to the target gear.

Within the diagnostic examination, a test was also carried out on the vehicle being stationary (Fig. 9). During such a test, the vehicle engine runs with its idle speed (the engine accelerator position should not be changed for the whole time of the test), the service brake pedal is kept depressed, and the drive mode selector lever is set to "P". The test is started by shifting the drive mode selector lever from "P" to "D", in result of which the main ATF pressure p_g rises. The time of the main pressure p_g being built up from zero to the normal operation pressure is the time lag t_{LT} of switching to another AT operation program (i.e. from "P" to "D" in this case). In the example presented (see Fig. 9), the time of the main pressure p_g being built up (the time lag t_{LT}) was 1.9 s. In practice, this is the time of filling the actuator of clutch "A" and hydraulic damper "5" (Fig. 4) at the idle speed of the vehicle engine. For the hydraulic control system of the automatic transmission under test, no limit has been specified in the service manual for the time lag t_{LT}. In the diagnostic signal presented as an example, the time lag t_{LT} value is similar to the value generally observed at the diagnostics of automatic transmissions (at the time lag test). The technical uniqueness, however, lies in the measurement method, which is based on recording the pressure vs. time curve. Such a method eliminates the error of measuring the time with the use of a stopwatch; at the very short time of the process under test (about 2 seconds), the values of this error may be significant. Moreover, the value of another diagnostic parameter is determined at the test carried out on the vehicle being stationary, i.e. the main pressure value p_g prevailing when the engine runs with its idle speed and the drive mode selector lever is set to "*Drive*". The limit values of this parameter are specified in the service manual as p_{gDbj} = 630–710 kPa [10]. In the example presented, the main pressure value was lower than the acceptable minimum, specified as p_g = 630 kPa (Fig. 9).

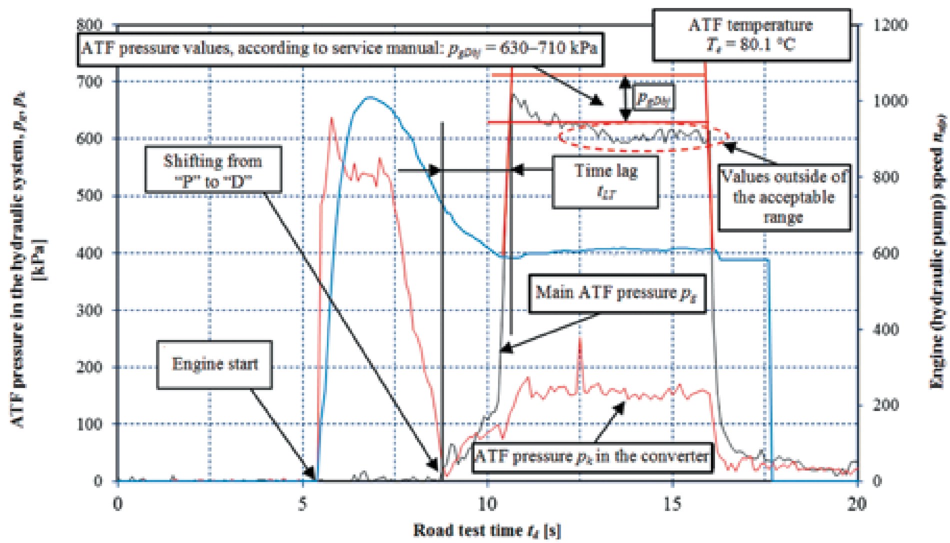

Fig. 9. Values of ATF pressures p_g and p_k in the hydraulic system and of engine (hydraulic pump) speed $n_{s(p)}$ vs. time t_d of the test on the vehicle being stationary

In all the test results presented, fluctuations in the pressure values were noticed. The fluctuations can be explained as a consequence of periodic variations in the ATF flow rate, resulting from cyclic nature of operation of the displacement parts of the hydraulic pump and from external excitations in the form of mechanical vibrations acting on hydraulic system components and transmitted from the vehicle as a whole to the wet clutch involved and then from the clutch to the hydraulic fluid via the actuator piston [9, 16].

The presented methods of assessment of the technical condition of hydraulic AT control systems are exclusively applicable in the conditions when the early symptoms of transmission malfunction (such as sporadic slippage, noise, perceptible jerks at gear changes, indicating partial serviceability of the transmission) can be noticed and a test drive in normal operation conditions still can be carried out, during which fluid pressures, gear-down change time, and time lag of switching to another AT operation program could be measured as appropriate. If a test drive in normal operation conditions cannot be carried out (because of total unserviceability of the transmission), the method presented is useless for the AT diagnostics.

In such a case, other diagnostic methods should be employed. One of them is the assessment of internal leak-tightness of the hydraulic AT control system. Apart from the electrohydraulic controller (where internal leaks through hydraulic gaps are an intrinsic feature of the controller construction), internal leaks may occur at actuator piston seals as well as at static and dynamic seals of fluid flow passages. The actuator piston seals undergo wear and tear, rubbing off, and degradation (ageing) of the material (rubber) they are made of. The dynamic seals of fluid flow passages are chiefly worn by abrasion and the static rubber seals are subject to ageing and cracking due to multiple drops and growths in the ATF pressure and attack of the fluid under high working temperatures. When a seal fails, the fluid flows from a section remaining under the working pressure to spaces where the atmospheric pressure prevails, which results in ATF flow rate losses (internal leaks) and pressure drops.

In this method, automatic transmission fluid (ATF) at its normal working temperature is forced under pressure into the hydraulic system section under test. The diagnostic signal is the rate of ATF flow through the leaking parts of the hydraulic system section or the time of pressure drop within a predefined range of pressure values when the fluid supply is disconnected from the system section under test. This method requires, however, that additional tests should be carried out to determine the acceptable limits for the quantities measured and a special test facility must be used; moreover, the electrohydraulic controller usually has to be removed.

The assessment of the technical condition of a hydraulic AT control system by measuring the internal leak-tightness is not popular in the AT diagnostics, but it is very often used for diagnostic testing of other hydraulic devices.

5. Conclusions

The experimental research carried out on the diagnostic signals obtainable from the hydraulic control system of an automatic transmission (AT) has made it possible to formulate conclusions as presented below.

1) The gear-down change time $t_{4 \to 2KD}$ measured for the "*kick-down*" function being performed may be a diagnostic parameter used to assess the slippage of AT clutches and brakes and the operation of the lock-up clutch. However, this requires additional tests for the acceptable limit of the gear-down change time to be determined.

2) The time lag t_{LT} of switching to another AT operation program (i.e. from "*Park*" to "*Drive*" in this case, manifesting itself by the main pressure being built up from zero to the value of the normal operation pressure) is a diagnostic signal that has already been in use, but the method of measuring this signal raises doubts (because of time measuring error and subjectivity of diagnostic engineer's reactions, i.e. synchronization of starting the time and system response measurements). The proposed method of measuring the time lag t_{LT} radically eliminates this problem, as the value of the time lag t_{LT} is read from a graph (Fig. 9).

3. The presented methods of assessment of the technical condition of hydraulic AT control systems are exclusively applicable in the conditions when the early symptoms of transmission malfunction (partial serviceability of the transmission) can be noticed and a test drive in normal operation conditions still can be carried out, during which the diagnostic signals could be measured as appropriate. If a test drive in normal operation conditions cannot be carried out (because of total unserviceability of the transmission), the method presented is useless for the AT diagnostics.

4. In the case that a test drive in normal operation conditions in impracticable, the technical condition of a hydraulic AT control system may be assessed by measuring the internal leakage, which may result in excessive ATF pressure drops in the control system clutch and brake actuators and cause the automatic transmission to malfunction. This, however, would require additional tests to be carried out.

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