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EFFECTS OF BASE COMPONENTS ON AUTOMATIC TRANSMISSION FLUID REOLOGICAL CHARACTERISTICS

Abstract

The development of new automatic transmission designs, the new quality requirements as well as the extended lubricant life have an influence on the constant development of new lubricant formulations for automatic transmission fluids. Their reological properties matter a lot in meeting those requirements. The kinematic viscosity at high and low temperatures is a very important lubricating oil characteristic, which needs to be retained within the certain values during its lifetime. The elastohydrodynamic lubricating film needs to be maintained along the whole range of operating temperatures. When using it at low temperatures gear change needs to be easy.

The paper presents how to meet performance requirements in regard with the specifications by the proper selection of base components conforming ATF DEXRON III formulations.

1. Introduction

Lubricating oils for automatic transmissions are used for lubrication in a broad application range. First of all they apply to automatic transmissions in passenger cars and heavy load commercial vehicles/buses, power steering on road and offroad vehicles, synchronized manual transmissions, as well as the hydraulic oil for industrial and mobile equipment and ship hydraulic systems.

The development of the new automatic transmissions designs, as well as the market requirements for the reduced fuel consumption and the reduced harmful exhaust gass emission challenge the manufacturers of lubricants for automatic transmissions to produce new lubricant formulations with improved characteristics, as well as with the extended drain period for ATF lubricants.

2. Overview of specifications and quality requirements

The oil quality levels for automatic transmissions as well as their operating properties are defined by the specifications of designers and manufacturers of automatic transmissions or vehicles equipped with them. These specifications define the procedures for issuing an approval for the application.

2.1 Specifications

Specific designs of automatic transmissions caused the differences among the specifications of different manufacturers. There are differences between the American and European OEM specifications. American manufacturers of automatic transmissions emphasize the lubricant quality for automatic transmissions of passenger cars, as oppose to European manufacturers which produce high quality lubricants for automatic transmissions of commercial vehicles.

The specifications of American designers and manufacturers:

- DEXRON®
- MERCON®
- ALLISON C-4
- CATEPILLAR TO-4

The specifications of European designers and manufacturers:

- Mercedes Benz (Daimler AG) MB Blatt 236
- MAN 339
- ZF
- VOITH G 607
- RENK

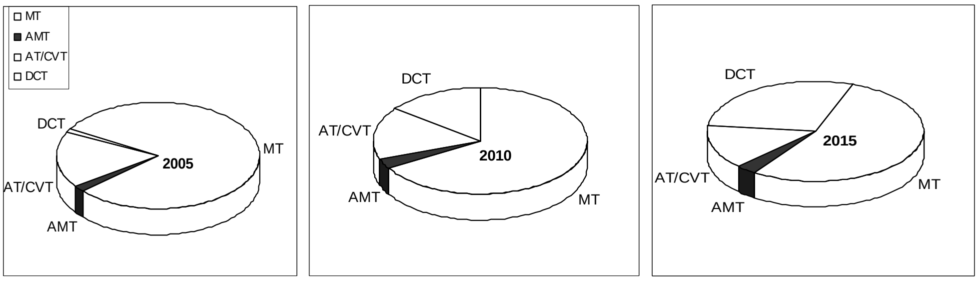
The greatest impact on the quality development of ATF lubricants is being made by the well known car manufacturers in the USA like General Motors (GM) and Ford with its known DEXRON® and MERCON® specifications.

The greatest amount of ATF oils in Europe is produced according to the specifications of designers and manufacturers of automatic transmissions and vehicles. The most common application of ATF lubricants in Europe is in automatic transmissions of commercial vehicles, while in the USA these lubricants are mostly used in passenger cars. These are the types of transmissions:

- MT (Manual Transmission)
- AMT (Automatic Manual Transmission)
- AT (Automatic Transmission)
- CVT (Continuously Variable Transmission)
- DCT (Dual Clutch Transmission)

Well known designers and manufacturers of transmissions predict the increase of DCT transmissions application by the year 2015 in Europe, while the use of AT/CVT transmissions will keep the same trend (Picture 1). The conventional manual transmissions are still mostly used in Europe. Their application will be reduced by approximately 20 % by the year 2015.

Figure 1: The distribution of the European market according to the types of the transmissions



2.2 Quality requirements for ATF lubricants

All the mentioned specifications define the requirements for the operating characteristics of lubricants for automatic transmissions. Oil formulations for automatic transmissions due to their broad range need to meet different requirements and quality in the actual application. They need to achieve good lubrication of planetary gears within the automatic transmissions and good heat transmission. They need to operate as the hydraulic lubricant when applying gear changes in operation of transmission and they need to have good antiwear protection. Lubricant has to be compatible with all the system components and provide a safe operation at high and low temperatures and thus exhibit an extended drain period.

Apart from these application characteristics, ATF oils also have the following operating characteristics:

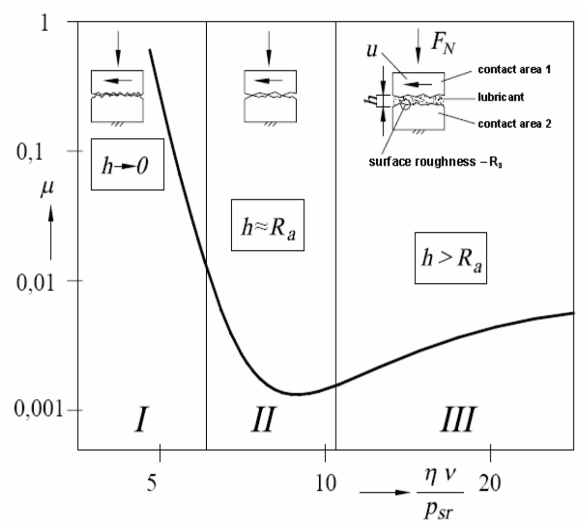
- good reological characteristics
- appropriate friction characteristics
- high oxidation and thermal stability
- corrosion protection
- wear protection and extreme pressure resistance
- compatibility with different materials
- good antifoaming properties
- good dispersant and detersive properties

2.2.1 Reological characteristics

Reological characteristics of the lubricants assume adequate viscosity under high and low temperatures which, in application, has to be kept within prescribed requirements. Elastohydrodynamic lubricating film needs to be preserved in the whole range of operating temperatures. There are three types of lubrication: borderline lubrication, mixed lubrication and full film lubrication (Figure 2).

With borderline lubrication, the lubricating film is not thick enough to prevent contact between surfaces; with mixed lubrication a lubricating film is partly damaged, so there is a partial contact between contacting surfaces. With full lubricating film, the lubricated surfaces are totally separated by the continuous lubricant film. This kind of lubrication can be hydrodynamic and elastohydrodynamic lubrication.

Figure 2: Conditions and types of lubrication



p_{sr} - average pressure in lubricant film, N/mm²
η - dynamic viscosity of lubricant, MPas
h - sliding speed between two contact areas, m/s
μ – coefficient of friction

- borderline lubrication (***I***)
- mixed lubrication (***II***)
- hydrodynamic lubrication (***III***)

The appropriate characteristics at low temperatures are important for the unobstructed operating of automatic transmissions. Viscosity at low temperatures is stated as dynamic viscosity at –40 ^{0}C, measured by Brookfield viscosimeter. The limit values for dynamic viscosity depend on the type of an ATF lubricant. Due to mechanical stress, to which ATF lubricant is exposed in application, molecules of higher molecular mass are being broken down into smaller ones which leads to viscosity decrease. ATF lubricants need to have a high viscosity index, which means a small viscosity change in regard to the temperature changes and they also need to be shear stable when applied. The following text explains how we can achieve stable reological characteristics during the application by the proper selection of base oils and additives in lubricants for automatic transmissions.

2.2.2 Friction properties

One of the most important operating characteristics influencing the reliable operation of transmissions is a friction coefficient. An ATF lubricant needs to retain the required values of the friction coefficient during the application period because the lubricants with high friction coefficient can cause wear as well as the inefficient transmission of power in the automatic transmission and impact heat release.

2.2.3. Thermal and oxidation stability

The extended drain period of the oil filling requires good oxidation and thermal stability for ATF lubricants. This can be achieved by the proper selection of base oils in the formulations of ATF lubricants. Thus, base oils of API groups II, III and IV are selected since they have better thermal and oxidation properties.

2.2.4 Antiwear properties

Lubricants for automatic transmissions need to have the required antiwear properties. This prolongs the durability of the transmission material which also means longer lifetime of a specific lubricant.

2.2.5 Corrosion stability

Mineral oils tend to create hydrofobic films on firm surfaces, or in other words, they show the natural anticorrosive effect. Mineral oil attacks metal surfaces only when it contains greater amounts of protons which occur as the products of oil aging or they are contained in additives. Natural protective anticorrosive effect of base oil in an ATF lubricant formulation is not sufficient so corrosion inhibitors are added. They need to be compatible with other components in the formulations.

2.2.6 Other characteristics

All the other characteristics of oils for automatic transmissions are also important so the lubricant manufacturers and designers have to simulate the actual application conditions while testing in order to reach appropriate formulations.

3. Lubricant formulations for automatic transmissions

Generally taken every lubricant contains approximately 90 % of base oils; additives make the rest of it in order to improve the properties of base oils. Additives work as: flow point improvers, shear stability improvers, viscosity index improvers, antiwear and extreme pressure additives (EP/AW), antioxidants, corrosion inhibitors, antifoamers and dispersants.

The selection of the base oils in lubricants is extremely important since in that way good reological characteristics and oxidation stability is achieved before additives addition.

3.1 Base oils

According to the physical and chemical properties, base oils are divided into 6 groups according to API (American Petrol Institute) classification.
Base oils are produced by the following technologies:

1. Classic or solvent technology

2. Hydrocracking technology
3. Hybrid technology

In the classic technology application the undesirable components are removed by physical methods, which means that the compound structure is not changed, while with the hydrocracking and hybrid technologies it is changed. For example, aromatic hydrocarbons, being the undesirable compounds, are tranformed into cycloalcanes (naphtenes). Base oils produced by the classic technology require a specific type of petroleum (for example, with paraffines and naphtenes) as a precondition for gaining good quality base oil. Other two technologies do not require a specific petroleum type due to the chemical changes of transforming olefins and aromates into paraffines and naphtenes.

Table 1: Base oil classification according to physical and chemical properties

Group	Content	Saturated hydrocarbons, %m/m	Sulphur, % m/m	VI
I	Conventional base oils	< 90	> 0,03	80 -120
II	Non-conventional base oils	≥ 90	≤ 0,03	80 – 120
III	Non-conventional base oils with high VI	≥ 90	≤ 0,03	≥ 120
IV	Synthetic base oils	Polyalphaolefins (PAO)		
V	Other base oils	Base oils which are not included in groups I,II,III,IV or VI		
VI	Synthetic base oils	Polyinternalolefins		

3.2 Additives

In oil formulations for automatic transmissions we use additive packages which contain functional additives with antiwear and high pressure load resistance effect (EP/AW), like antioxidants, corrosion inhibitors, antifoamers and detergents. Also, some additives for the improvement of reological characteristics are added into a package or they form a separate package. These additives are shear stable and have good dispersive properties. Polymer additives of this sort are usually based on polyalcilmethacrylates (PAMA) and styrene-ester copolymers.

4. Experimental part

The goal of this paper was to formulate the oil for automatic transmissions of semisynthetic basics, with the quality level in regard with GM DEXRON III and the European OEMs (ZF, MAN, MB).

4.1 Composition of lubricants for automatic transmissions

In blending samples were base oils of API groups I, II, III and IV used. The group I base oil was SN 150. The groups II and III base oils were hydrocracked base oils and the group IV base oils were PAO 2 and PAO 4. Their physical and chemical properties are shown in Table 2.

There were two combinations of base oils: polyalphaolefins (PAO) and base oil SN 150 (Table 4) and a combination of hydrocracked oils (HK), of API group II and III, with base oil SN 150 (Table 5). The goal of this test was to determine the proper ratio of different base oils for achieving the quality level of GM DEXRON III. The limit values are taken from the ZF list TE-ML 14B for service filling of ATF lubricants, of semisynthetic base for commercial vehicles, with oil drain due after 60000 km (produced 2004-12).

Table 2: Physical and chemical properties of base oils, typical properties

BASE OILS	METHOD	PAO 2	PAO 4	HK, API II	HK, API III	SN 150
Kinematic viscosity - at 40^0 C, mm^2/s	ISO 3104	5,1	16,8	12	26	32,7
Kinematic viscosity - at 100^0 C, mm^2/s	ISO 3104	1,7	3,9	3,0	5,1	5,4
Viscosity index	ISO 2909	219	124	111	126	99
Flow point, ^{0}C	ISO 3016	- 73	- 73	- 30	- 15	-9
Flash point (COC), ^{0}C	ISO 2592	180	219	198	240	218
Density at 15^0 C, kg/m^3	ISO 2719	798	819	825	835	872

When developing this formulation of ATF lubricant 3 additive packages (A, B, C) were used. The achieved physical and chemical properties influenced the final selection, as well as the cost price of the final product. These additive packages contained components which work as: flow point improvers, shear stability improvers, viscosity index improvers, antiwear and extreme pressure additives (EP/AW), antioxidants, corrosion inhibitors, antifoamers and dispersants.

4.2 Test methods

Methods used in the testing of the formulations are shown in Table 3. Kinematic viscosity at 100 ^{0}C, dynamic viscosity at -40 ^{0}C, measured with Brookfield viscosimeter, and shear stability stated through the kinematic viscosity at 100 ^{0}C, measured after the test were monitored. Shear stability was tested on tapered roller bearing, according to the DIN 51350-6-KRL/C method in a 20 hours period.

Table 3: Test methods in the production of ATF lubricants formulations

METHOD	PROPERTY	Units
ISO 3104	Kinematic viscosity - at 40^0C	mm^2/s
ASTM D 2983	Dynamic viscosity - at 40^0C	mPas
DIN 51350-6-KRL/C 5000 N, 60 ^{0}C, 20h, 1500 min	Shear stability - kinematic viscosity at 100 ^{0}C	mm^2/s

4.3 Test results

Tables 4, 5 and 6 show ATF DX III formulations of the lubricants with different types of base oils and different additive packages and their physical properties.
Figure 3 shows the relation between the selected formulations of ATF lubricants and their cost price.

Table 4: ATF DX III formulations with polyalphaolefins (PAO) and base oil SN 150

FORMULATIONS	FA/1	FB/1	FC/1	FA/2	FB/2	FC/2	ZF list TE-ML 14B
PAO 4 / SN 150, %	57 / 43	75 / 25	83 / 17	-	-	-	
PAO 2 / SN 150, %	-	-	-	21 / 79	23 / 77	27 / 73	
Additive package A %	+	-	-	+	-	-	
Additive package B (1) %	-	+	-	-	+	-	
Additive package C (2) %	-	-	+	-	-	+	
Kinematic viscosity - at 100^0 C, mm^2/s	7.25	7.71	7.46	7.13	7.85	7.26	min. 7.0
Dynamic viscosity, mPas - at –40 ^{0}C, (Brookfield)	8 200	6 410	7 710	19 400	20 000	19 800	max. 20 000
Shear stability, KRL - v/100 ^{0}C after shear., mm^2/s	5.80	5.54	6.56	5.34	5.35	6.45	min. 5.5

(1) Additive package B → 1.6 % higher than A
(2) Additive package C → 6.8 % higher than A

Table 5: ATF DX III formulations with hydrocracked base oils (HK) and base oil SN 150

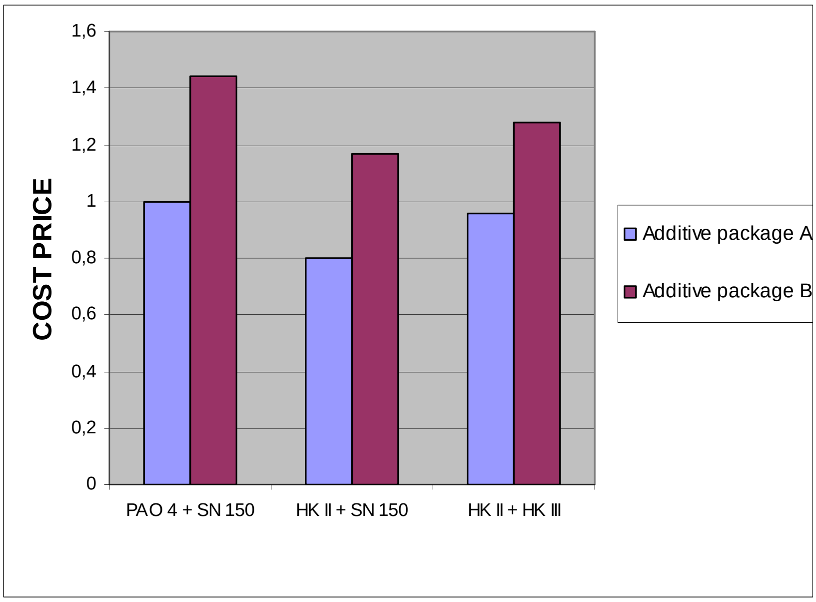
FORMULATIONS	FA/3	FB/3	FC/3	FA/4	FB/4	FC/4	ZF list TE-ML 14B
HK, API II / SN 150	41 / 59	52 / 48	56 / 44	-	-	-	
HK, API II / HK, API III	-	-	-	28 / 72	37 / 63	49 / 51	
Additive package A %	+	-	-	+	-	-	
Additive package B ** %	-	+	-	-	+	-	
Additive package C *** %	-	-	+	-	-	+	
Kinematic viscosity - at 100^0 C, mm^2/s	7.37	7.74	7.27	7.31	7.,91	7.25	min. 7.0
Dynamic viscosity, mPas - at –40 ^{0}C, (Brookfield)	18 200	15 800	18 800	12 200	11 000	11 600	max. 20 000
Shear stability, KRL - v/100 ^{0}C after shear., mm^2/s	5.50	5.35	6.33	5.73	5.58	6.46	min. 5.5

(1) Additive package B → 1.6 % higher than A
(2) Additive package C → 6.8 % higher than A

Table 6: Formulations of ATF lubricants within additive packages

FORMULATIONS	Additive package A				Additive package C			
	PAO4 + SN150	PAO2 + SN150	HK II + SN150	HK II + HK III	PAO4 + SN150	PAO2 + SN150	HK II + SN150	HK II + HK III
Kinematic viscosity at 100⁰ C, mm^2/s	7.25	7.13	7.37	7.31	7.46	7.26	7.27	7.25
Dynamic viscosity at –40 ⁰C, mPas	8 200	19 400	18 200	12 200	7 710	19 800	18 800	11 600
Shear stability, v/100 ⁰C, mm^2/s (after test)	5.80	5.34	5.50	5.73	6.56	6.45	6.33	6.46
Cost price	1	-	0.80	0.96	1.44	-	1.17	1.28

Figure 3: Comparison of ATF lubricants and their cost price



5. Conclusions

GM DEXRON III quality level ATF lubricant on semisynthetic basics offers following:

– Additive packages A and C offered the acceptable reological characteristics of ATF lubricants of GM DEXRON III quality level.

– Additive package C offered the best results in all the base oils combinations, but is most expensive (approx. 40 %) when related to the package A (Fig. 2).

- The combination of PAO 4 and base oil SN 150 shows better reological characteristics than the combination PAO 2 and SN 150. This confirmed the fact that lubricant formulations tend to use base oils of similar viscosity grades.
- The combination of two hydrocracked oils offered better reological characteristics than the combination of the hydrocracked oil with SN 150; the cost is 15% higher.
- Better reological characteristics are shown with the combination of PAO 4 and SN 150 than with the combination of hydrocracked oils of II and III API groups. Although the costs are slightly higher (4 %), this combination is acceptable.
- When issuing the approval for the use of ATF lubricants of semisynthetic and synthetic basics with the approved additives (ZF list TE-ML 14B and C), ZF requires the additional tests of friction properties and the compatibility test with seals. With these lubricant types the hydrocracked oil portion and PAO is more than 50 %.
- More stringent demands for the kinematic viscosity after the shear stability test (MERCON V and DEXRON VI) require the use of greater amount of shear stable polymer additives and the use of the groups II, II+, III and IV base oils. Better reological characteristics and oxidation resistance is achieved in this way.
- Base oils of better quality and the improved additive technology provide the extended life period for lubricants, which leads us to “oil fill for life”, which seems not very good for lubricant manufacturers.

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UDK	ključne riječi	key words
621.892 : 621.833	ulje za automatske prijenosnike	automatic transmision fluid
665.765	bazne komponente mazivog ulja	lubricating oil base components
532.135 : 665.765.03	reološka svojstva maziva	lubricant rheologic properties

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