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Diagnostics of hydraulic fluids used in aviation

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Abstract. Diagnostics is a maintenance industry that monitors performance, parameters, and follow–up. Diagnosing hydraulic fluids means comparing the parameters of the used hydraulic fluid sample to the parameters of the clean fluid. It is also essential to monitor the limit values either by the aircraft manufacturer or by the manufacturer of the hydraulic fluid. This means that the manufacturer recommends the limitations of the liquid parameters. The measurements of the fluid samples give an overview of the liquid quality. Most businesses focus on so–called proactive maintenance. The main senses and objectives of proactive maintenance are: lubricant sample analysis, lubricant status, machine status, next step recommendation, database saving and trend analysis. This article focuses on the quality of hydraulic fluid focused in aviation. The aim of the article was to determine the properties of the hydraulic fluid used in the A320 aircraft family, determine the interval of its exchange. Monitoring the state of the hydraulic fluid could contribute to the timely detection of the problem, thus avoiding a failure of the device or the system as a whole. The tracking proposal is an integral part of this article.

Key words: particle analysis, control interval, kinematic viscosity, hydraulic fluid, cleanliness code.

INTRODUCTION

Airbus A320 is built by using of Hi–Tech materials such as composites composed of carbon fiber or kevlar or glass fiber and titanium. Due to the light components, the aircraft is as light as possible. The first flight of the A320 took place on February 22, 1987. Certification and supplies began some days later. Air France and British Airways started commercial flights with the A320 in May 1987. The A320–100 had the range of 3,500 km. The range of up to 5,500 km was extended for versions A320–200 after structural modifications and placing the winglets wing ends. Winglets reduce tensile stress, reduce induced resistance and fuel consumption. After the winglets were installed, the A320–100 production was completed and the production of the A320–200 continued (Airbus S.A.S, 2008; Planes.CZ, 2017).

The extended version of the A320, the A321 has been designed. The body of the aircraft is longer being 6.93 meters than A320. The flaps were modified and the chassis was reinforced. The new version was capable to accommodate 176 passengers. The airplane was equipped with two extra emergency exits. The first flight was made on March 11, 1993 (Airbus S.A.S 2008, Planes.CZ).

Another version of the A320 is a smaller A319. This version combined A320 and A321 drives. It is 3.73 meters shorter than the A320 and accommodates only 130 passengers. The range is 5,000 km. The airplane is also compiled in Hamburg by DASA. The airplane was first presented in Farnborough in 1993.

Table 1 lists the parameters of the entire A320 Family Airbus S.A.S 2008

Table 1. A320 Family Specifications (Airbus S.A.S, 2008)

Type	A318	A319	A320	A321
Length	31.44 m	33.84 m	37.57 m	44.51 m
Wing span	34.09 m	33.91 m	34.09 m	34.09 m
Drive units	2 Pratt & Whitney PW–6000 or CFM International CF56–5	98 CFM International CFM56–5A or International Aero Engines IAE V2500–A5s	CFM International CFM56–5A1 or CFM56–5A3	International Aero Engines V–2530–A5 or CFM International CFM–56–5B1
Maximum range	2,780 km	3,391 km	4,843 km	4,907 km

The life of the aircraft is 20 years – approximately 48,000 flights, the average duration of the flight being one hour and twenty–five minutes. The airplane is approved for 24,000 flights with a threshold for the first inspection of the state of construction after 20,000 flights. The design criterion for the chassis is 60,000 cycles.

The booster system operates at a pressure of 0.555 MPa (8.06 PSI). The pressure relief valve is set at 0.579 MPa (8.40 PSI). The maximum fuel volume in the configuration of the two main tanks is 15,609 liters. The configuration with three fuel tanks is 23,859 liters with 2% reserve for thermal expansion (Planes.CZ). The aircraft is equipped with three continuous hydraulic systems: Green, Yellow and Blue. Each is supplied from its own tank. The normal system pressure is 20.68 MPa (3,000PSI) (Airbus S.A.S 2008).

The **green system** controls: chassis opening and closing including bow chassis control, normal braking system, engine thrust reversing no.1 (left side), flight control elements, power transmission unit, side damper (in–flight stability), take–off and landing flaps, moving leading edges (slots).

The **blue system** controls: flight control elements, Constant Speed Motor/ Generator, take–off and landing flaps and floating leading edges (slots).

The **yellow system** controls: cargo doors, backup brakes and parking brakes, engine thrust reversing no.2 (right side), flight control elements, power transmission unit, side air damper (in–flight stability), take–off and landing flaps (Airbus S.A.S, 2008; Lufthansa Training Manual, 2017).

Green system (System 1) is powered by a pump located on the engine number 1. Blue system (System 2) is powered by an electric drive pump. Yellow system (System 3) is powered by a pump located on motor number 2. This system can also be powered by an electric drive pump which allows ground manipulation when the engines 1 and 2 are switched off.

Diagnostics is a maintenance industry that monitors performance, parameters, and follow–up. Diagnosing hydraulic fluids means comparing the parameters of the sample taken with the clean fluid parameters. Monitoring of limit values is essential. The manufacturer recommends the limitations of the liquid parameters. The analysis obtains an overview of the liquid state and determines the wear and tear (Veselá et al., 2014; Hönig, 2015). Proactive maintenance is currently the most common. The objective is to analyze the lubricant sample, determine the condition of the lubricant and determine the state of the machine. The aim is also to recommend the next procedure and store the result in the database, make the trend analysis, and do the maintenance quickly and accurately. The method is very effective and reduces the cost of downtime, spare parts, operational substances and maintenance work (Aleš et al., 2012; Aleš et al., 2016; Hönig & Orsák, 2016).

It is necessary to know the construction materials for monitoring the condition of the machine. Oil is a medium bearing wear particles (Hönig & Hromádko, 2014; Hönig et al., 2014a). The change in the fluid properties may indicate damage of the machine (Hönig et al., 2014b). The kinematic viscosity at 40 °C is an important parameter as well as the cleanliness codes according to NAS 1638, ISO 4406 and ISO 4407. The hydraulic liquid is phosphate–ester base and is designed for commercial airliners. The liquid has higher thermal stability, lower density and more of anti–corrosive effects than previous types of hydraulic fluids. The EXXON HyJet IV A–plus meets all the requirements of aircraft manufacturers. EXXON HyJet IV A–plus is used as a refill for hydraulic systems of transport aircraft, where the former–ester base is recommended (ExxonMobil).

Table 2. Basic parameters of pure liquid specified by the manufacturer (Airbus S.A.S, 2008)

Parameter	Standard	EXXON HyJet IV	Limit
Kinematic viscosity at 40 °C, $mm^2 s^{-1}$	ASTM D445	10.55	± 20% 8.44–12.66
Density at 25 °C, $kg m^{-3}$	ASTM D4052	996	99–1,005
Acid number, mg KOH g^{-1}	ASTM D974	0.4	1.5 max.
Water content, %	ASTM D6304	0.1	0.2 max.
Cleanliness Code NAS 1638	–	4	9 max.
El. Conductivity, microSiem cm^{-1}		1.4	0.5 min.

The basic control intervals are:

Pre–Flight and Flight check: performed before each flight, no more than two hours before scheduled departure. Tasks may alternatively be performed by the flight crew as part of the approved pre–flight checklist (Planes.CZ, 2017).

Daily check: performed daily, time may not exceed 36 hours from the previous one. **Weekly check:** every 8 days.

A check level A

1A every 600 flight hours or 100 days;

2A every 1,200 flight hours;

4A every 2,400 flight hours.

C check level C

1C every 20 month/6,000 flight hours/4,500 flight cycles;
2C very 40 month/12,000 flight hours/9,000 flight cycles;
3C every 60 month/18,000 flight hours/13,500 flight cycles;
4C every 80 month/24,000 flight hours/18,000 flight cycles;
IL check: structure review every 5 years
D check: structure review every 12 years
5–year check: additional check every 5 years
10–year check: additional check every 10 years

The main fatigue threshold is set to 24,000 flight cycles or 42,000 flight hours (Airbus S.A.S 2008; Lufthansa Training Manual, 2017).

The aim of the article was to determine the quality of the hydraulic fluid used in the A320 aircraft family, determine the interval of its exchange and create a measurement methodology. The quality of the EXXON HyJet IV A–plus liquid (Table 2) was monitored.

MATERIALS AND METHODS

Samples are routinely taken at C Check and sent to German Lufthansa Laboratory. The C Check has large intervals, so A Check has been selected (600 flight hours). Using the A Check, the interval is shorter and more samples can be taken than when using the C Check. The A Check can be defined as performing a functional check of the aircraft and its systems. It mainly focuses on checking features that are not routinely tested (backup systems, state–of–the–art signaling, etc.). The overview of analyzed aircraft and their age is shown in Table 3.

Sampling was performed within 1 year according to Lufthansa's subscription and analysis procedures. In the sampling, the contamination of the sample should be avoided. The sampling is done either in clean glass containers or in plastic containers. The aircraft was connected to a source and the hydraulic systems where activated for sampling.

Table 3. Overview of the analyzed Airbus A320 Family of Airline company

Age, year	Type
11	A321
	A321
6	A320
	A320
2	A320
	A320
	A320

The following tests were performed:

- Acid number according to ASTM D974
- Kinematic viscosity at 40 °C according to EN ISO 3104
- Density at 25 °C according to EN ISO 3675
- Cleanliness code according to NAS 1638 a ISO 4406 (Parker.com, 2018).

An automated evaluation of the cleanliness code is based on the microscopic analysis of the pollutant solids contained in the hydraulic fluid. The principle is to sum the amount of particles on a membrane filter with known area after the known volume of hydraulic fluid has been filtered through the membrane.

The result is a computerized code indicating the amount of solid impurities according to standards NAS1638 and ISO 4406. The Lambda DN 45 microscope with color CCD camera connected to Lambdasoft 2000 was used (Fig. 1 and Fig. 5).

Three measurements were made to determine the acid number, kinematic viscosity and density. The result is always the arithmetic mean of all measurements. For the determination of solid impurities and NAS 1638 10 images were scored vertically and 10 images horizontally on each filter.

Based on the measured results, Lambdasoft software was used and the software results are a completed statistical evaluation according to NAS 1638.

Figure 1. Lambda DN 45 microscope.

RESULTS AND DISCUSSION

The pure liquid had a purple color and the color darkened due to wear. The used liquid was brown. The NSA307110 standard introduces the word transparent. Lufthansa has the parameter marked as 'pure' according to NSA307110.

The clean liquid should have an acid number smaller than 0.15 mg KOH g^{-1}. The calculated average acid value was 0.41 mg KOH g^{-1}.

Fig. 2 shows that the acid number was reduced by refilling of the liquid. The acid number increases gradually. The limitation was satisfactory.

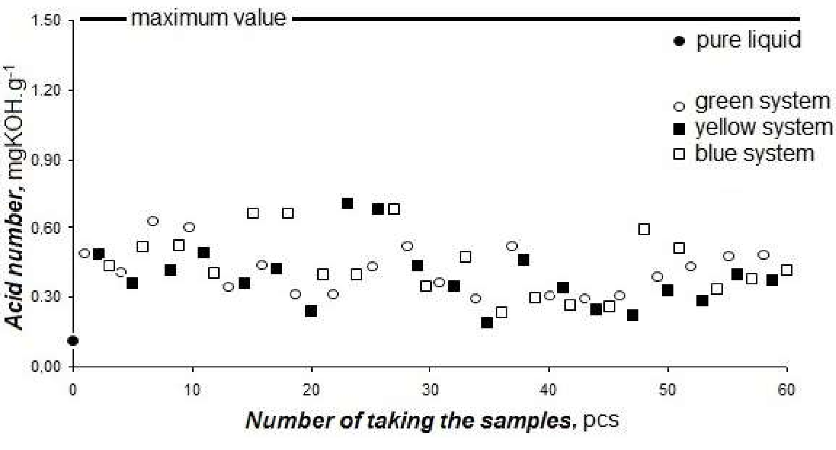

Figure 2. The trend of the acid number.

The results of the kinematic viscosity fluctuated slightly (Fig. 3). This may be caused by an admixture of another liquid or increased water content. The average of viscosity value was 6.67 $mm^2\ s^{-1}$.

The values of kinematic viscosities where close to the lower limit. The results of the kinematic viscosity measurements guaranteed that the fluid is easy to pump, has low resistance to system startup and ensures good tightness and sufficient lubrication.

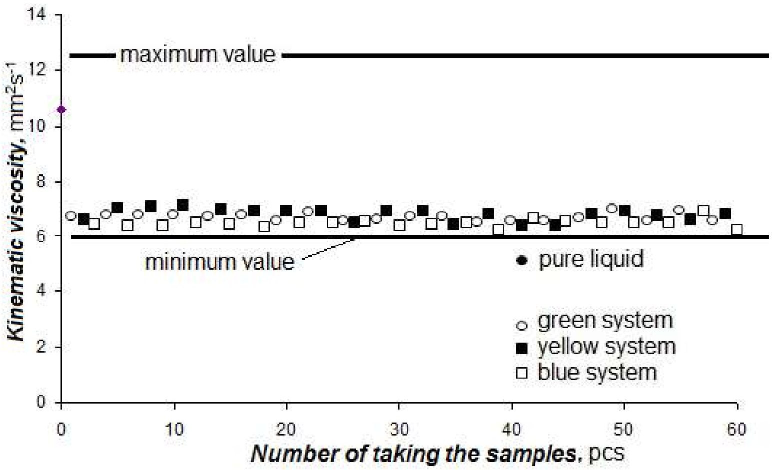

Figure 3. The trend of kinematic viscosity at 40 °C.

Fig. 4 shows that it would be advisable to adjust the maximum density value. The value is based on the Lufthansa Training Manual. Pure liquid has a tolerance field in the range 993 to 1,066 kg m^{-3}. The range of 990 to 1,020 kg m^{-3} would be preferable.

The most important parameter of the hydraulic fluid is the cleanliness code. Proper selection of the sampler is also important. The sampler should be made of glass or plastic. Plastic are used most often. Glass containers are more suitable for the cleanliness code. By friction of wall fluid, some metal particles can form grooves (Mihalčová & Hekmat, 2008).

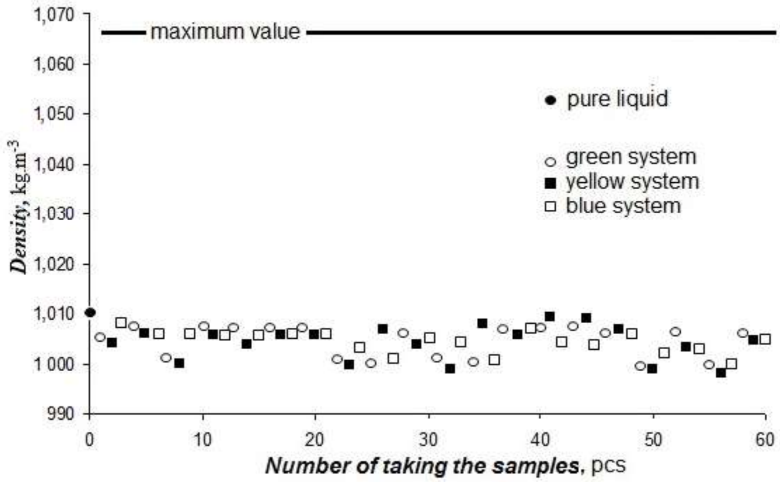

Figure 4. The trend of density at 25 °C.

In addition to NAS 1638, ISO 4406 is also used. The difference between them is that NAS 1638 refers to 100 mL of sample, ISO 4406 converts the particles to one milliliter.

The fluid system is continuously refilled and the hydraulic system is always properly controlled. The first replacement is therefore appropriate after the complete dismantling of the aircraft and replacing end–of–life parts with new ones (IL Check – every 5 years).

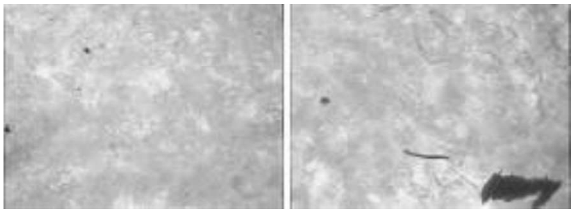

Figure. 5. Images from the Lambda microscope.

Two samples of the hydraulic fluid of the blue system exceeded the permitted values determined by the chemical analysis. It is necessary to make an immediate exchange regardless of the exchange interval (Fig. 6).

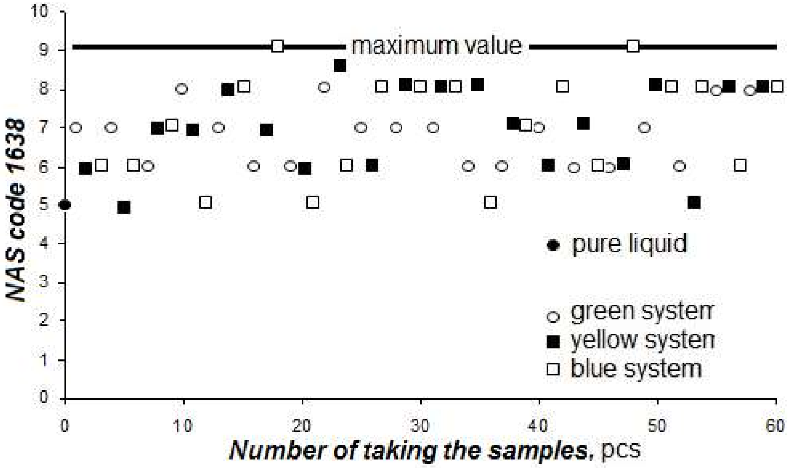

Figure 6. The trend of the cleanliness code.

It is important to analyze how much hydraulic fluids are added. The volume of the hydraulic fluid of the aircraft will be replaced in 13 months with the addition of 4 liters of liquid per month.

This may be one of the reasons why the fluid does not change. It is important to monitor and record the amount of liquid supplied. The analysis should be performed at least once every 6 months.

For economic evaluation, it is necessary first to quantify the price of filling of all hydraulic systems of the aircraft. The cost of one tank (0.946 liter) is 7.68 EUR. The total volume of fluid is shown in Table 4.

Table 4. The total volume of hydraulic fluid in A320

volume of the green system	23 L
volume of the yellow system	20 L
volume of the blue system	10 L
total volume	**53** L

For a capacity of 53 liters, 56 tanks of a total value of EUR 430 are needed. The basic lack of control is that the costs of each fill are not recorded and the exchange date is not determined. For this reason, it is not possible to calculate the exact cost savings associated with the exchange. Replacement of filter inserts is also important. Increased replacement means increased wear and therefore increased costs (Pexa et al., 2015; Pavlů et al., 2016). Another factor is downtime. By increasing the maintenance reliability, the back–ups to other lines can be used and downtime is shortened and costs will be saved. The measurement result can determine what is more cost–effective: changing the hydraulic fluid or introduces system monitoring and analysis. As a final consequence, the worst is the loss of prestige if the aircraft is shut down (Zhang et al., 2017).

CONCLUSIONS

Airlines have to take care of their fleet of transport aircraft at a very high level and take the highest safety.

Important factors in air transport are safety and reliability. Reliability is clearly the highest priority and costs are subject to this requirement. The measured values were evaluated and the procedure and interval of the hydraulic fluid change was designed. The exchange interval was set at 5 years. The limit of particle size was also identified. Immediate fluid exchange is required in this case.

The aim of the article was to determine the properties of the hydraulic fluid used in the A320 aircraft family, determine the interval of its exchange and create measurement methodology. The parameters analyzed where acid number, kinematic viscosity at 40 °C, density at 25 °C and cleanliness code. Based on the results, the following could be concluded. The average acid number was 0.41 mg KOH g^{-1}. The acid number increases by exploitation of the liquid and decreases by the fluid supply. The acid number limits are satisfactory. The average kinematic viscosity value was 6.67 $mm^2\ s^{-1}$. Different liquids or higher water content influences kinematic viscosity. The standard limit of the kinematic viscosity can be reduced to 12 $mm^2\ s^{-1}$ and optimal operation will still be ensured. Adjusting maximum density is also possible. According to the measured values, the interval may range from 990 to 1,020 kg m^{-3}.

Two samples of the hydraulic fluid from the blue system exceeded the allowed values determined by the chemical analysis and it is necessary to make an immediate exchange regardless of the exchange interval.

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