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Original Paper

Design and Application of Integrated Cooling System Against Temperature Risks of Metrobus 5th Axle Steering System

Esat Tekin[1], **İbrahim Yönel**[1], **İbrahim Bilen**[1]

[1]Ulaşım İç ve Dış Ticaret A.Ş., Bursa, Turkey

ORCID IDs of the authors: E.T. 0000-0002-7181-9684; İ.Y. 0000-0003-1812-3482; İ.B. 0000-0001-9985-5823.

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Abstract

Today, studies are carried out to extend the life of the oils used in commercial vehicles. There are many parameters that should be taken into account in these studies. In the study, especially due to the overheating problem of the hydraulic oil of the axles steered by hydraulic pressure, the radiator integration into the system was made in response to the oil overheating problem experienced in the 5th steerable axle of the Akia 25-meter bus. In this paper, subjects such as oil cooler selection, fan selection, and frame application around the radiator were emphasized. Necessary measurements were made on the system and compared with the results before and after integration. Evaluations were made in line with the results obtained from these comparisons. The oil cooler was applied with 600 mm length and 200 mm width, 2 fans with Ø268.5 mm diameter and 10''LP blowing capacity and 24V power were preferred. The system consists of 7 main parts: steering axle, hydraulic unit, hydraulic accumulator, oil cooler, oil filter, pump and oil tank. Steel pipes of Ø18 mm and Ø15 mm diameter are used on the line, and oil cooler connection is provided with 5/8'', 1/2'' and 3/4'' hoses. The hoses and pipes used in the connection line have been selected to be suitable for use in the discharge and return lines. When the connection temperatures reach 80° degrees, the fans of oil cooler is activated through the integrated system, and the oil temperature is reduced to 65°, thus eliminating the risk of temperatures reaching 130° degrees before integration. As a result, the problems arising from high temperatures have been prevented, and with the more efficient operation of the system, both the oil life has been extended and the service costs have been reduced.

Keywords: Bus, steerable axle, radiator, oil life.

1. Introduction

The oils used in metrobuses and the life of oils are extremely important. Especially in additional axles, different models are made on cooling systems in order to find solutions to oil temperature increases. Studies on this subject focus on oil life, generally. One of the main factors affecting oil life is effective cooling systems. The most important criterion to consider in the design of light commercial vehicles used in all weather and road conditions is durability. The performance of the engine and some auxiliary units that directly affect the engine is also extremely important. At this point, the importance of cooling system performance emerges. When the existing studies in the literature are examined, there are many studies ranging from the effect of radiator connections on durability to the analysis of fan inlet and outlet temperatures. Not only part-based, but also complete cooling system designs are among these studies.

When the publications on radiator durability are examined, the issue of thermal stress reduction is examined under two main headings: 1) Connection, 2) Side sheet. Allied Signal Inc. has developed different connection forms as a solution to thermal stresses on the radiator and cooling module [1,2]. The most important of the studies on the side sheet and the study carried out by Ford Global Technologies Inc., which is used today, has found a solution to thermal stress with different cuts on the side sheet [3].

Address for Correspondence:
Esat Tekin, e-mail: esat.tekin@ulasim-as.com

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Passive cooling strategies for improved heat transfer rates in automotive applications have been studied previously [4,5]. The heat transfer rate is expressed in terms of heat transfer surface area expansion and/or high thermal conductive materials. Different fin structures are used to expand the heat transfer surface area. Since unlimited surface expansion can create problems in terms of design, highly thermal conductive materials, carbon fibers, two-phase passive devices, etc. are integrated into radiator systems [6-8].

Bilge and Altıner designed a cooling system for rear-engined vehicles in a study they conducted, and they designed a more efficient cooling system by creating a new type of model in the light of the data obtained according to the results of the analysis, in which aerodynamic external flow analyzes and engine compartment thermal analyzes were performed [9]. On the other hand, it has been observed that the cooling simulations of the polyurethane coated vehicle steering wheel, which stands out as a different study, were made by Türkan, Etemoğlu, Çeğil. In this study, the roughness coefficient of the cooling channels, the flow rate of the coolant and the effect of the channel diameter on the cooling of the polyurethane coated vehicle steering wheel injected into the mold were modeled by simulation. As a result, with their model, it was observed that the cooling time was reduced by 24.2% when the channel diameter was reduced by 75%, and by 64.6% when the fluid flow rate was quadrupled [10].

In his thesis, Yaşar Mutlu emphasized the importance of the cooling system in vehicles and explained in detail the role of cooling systems influencing vehicle efficiency [11].

In 25-meter Akia buses, a new cooling system has been worked on in response to the oil temperature problems in the steerable axle and a radiator has been integrated into the system to eliminate the oil overheating problem. In order for the radiator fans to draw sufficient air, a frame was applied around the radiator. Appropriate diameters of pipes and hoses used between the steering piston and the radiator were determined and applied considering the suction and discharge lines. In this radiator integration, high temperatures have been prevented and the oil temperature has been reduced to 65°-80° degrees, which is considered appropriate.

2. Material and Method

2.1. Steerable Axle

Induction surface hardened low alloyed medium carbon steels are frequently utilized in essential automotive and machine applications that demand high fatigue resistance. The right combination of hardening depth and the magnitude and distribution of residual compressive stresses in the surface layer determines the fatigue behavior of induction-hardened components to a large extent.

Axles are connected within vehicles to provide two vital functions:

- Carry torque from the engine to the wheels via a planetary gear arrangement,
- Keep the wheels in relative alignment with each other and the vehicle's body. The circular motion of the drive wheels is maintained in most noncommercial vehicles by axle shafts, which are an essential component of the rear axle.

Two axle shafts, which are used as powertrain elements in construction machines hardened with induction heat treatment with SAE 4140H material stand-ard, were broken during operation. In this study, 2 failed axle shafts and 2 non-failed axle shafts were compared in order to determine the reason for the breakage.

Pieces were cut in regions A, B, C, and images were taken with a CARL ZEIZZ NEOPHOT 32, NIKON SMZ 1500 light microscope. The microstructure structure and hardened case depths of the parts were checked.

The additional axle we use is the rudder and driven axle. In heavy tonnage vehicles, it is a legally permissible axle that allows the drive axle load to be exceeded. If a vehicle is overloaded, it is used to lift the load in a healthy way and to increase the maneuverability of the vehicle. Additional axles can be designed to move in harmony with the front axles to increase the maneuverability of the vehicle. These axles are called maneuverable additional axles. The additional rudder axle shown in Figure 1 is the axle used in Akia 25 m long buses, and during this period of operation, the available axle oil data were taken from this part.

Figure 1. Akia LF25 steering axle

2.2. Radiator Integration

The most basic heat exchangers in terms of cooling systems are radiators. Since they are easy to use, can be supplied in almost any size, and have ease of connection, radiators were preferred in the cooling system in this study. As can be seen in Figure 2, the core of the radiator used in the system is supported by 24V fans with a length of 600 mm, a width of 200 mm, 2 units, and a diameter of Ø268.5 mm with a blowing capacity of 10''LP.

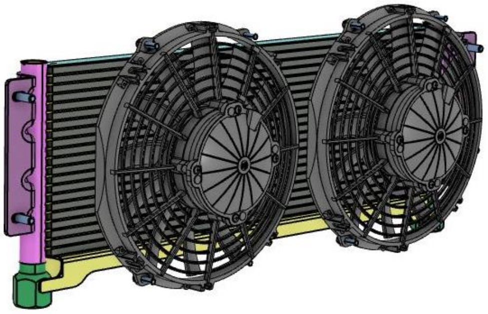

Figure 2. Oil cooler radiator

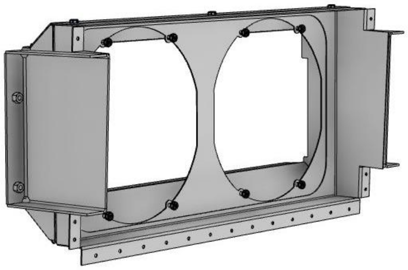

Figure 3. Oil cooling radiator frame

2.3. Special Airflow Design

It was found that when the radiator is placed directly, the fan does not draw enough air and therefore cannot reach the desired cooling. For this reason, it was determined that there was a need for a framework. A special design has been made to ensure that it can take the position and the air that the fan needs. In order to provide sufficient flow rate air required by the radiator integrated into the system, a frame design has been made to provide special air flow to the system. The frame, as can be seen in Figure 3, is located in the area within the green area that is the assembly line and is shown in Figure 4. In terms of being lightweight, 1.5 mm and 1 mm thick St37 materials were tried in the design studies and ideally St37 was evaluated as raw material and produced.

2.4. System Diagram

As can be seen in figure 5, the system consists of a steerable axle, hydraulic unit, hydraulic accumulator, oil filter, pump, oil tank, and radiator. This system works with hydraulic oil and pipes and hoses that provide the connection between the 7 main parts. The pump pulls hydraulic oil from the oil tank and allows it to enter the filter first and then into the hydraulic unit. The hydraulic unit then distributes the hydraulic oil and gives movement to the piston.

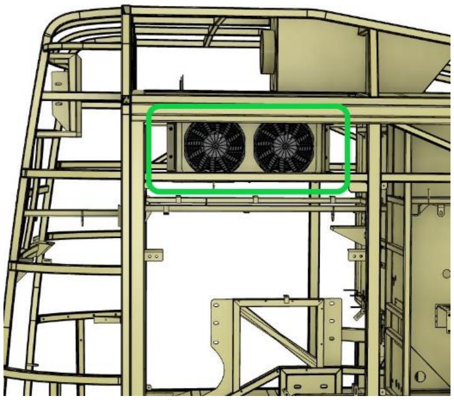

Figure 4. Location of the radiator

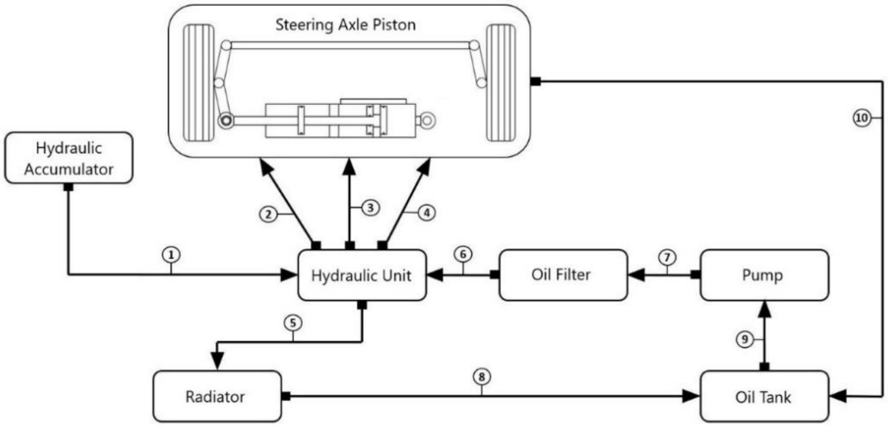

Figure 5. System diagram

Table 1 gives a list of pipe and hose selections that provide the connection. While making these choices, importance was given to the thickness of the compression and turning lines. Since there will be more pressure required in the pressure lines, small diameter pipes and hoses were preferred, and larger diameter hoses and pipes were used in the return lines than the pressure lines.

2.4.1. Steerable Axle Piston

On the piston on the steerable axle, there are 3 hydraulic oil inputs shown in blue in Figure 6 and 1 hydraulic oil outlet shown in red. These inputs allow the piston to move back and forth, allowing the additional axle to perform the steering task. The outlet sends the hydraulic oil back to the oil tank.

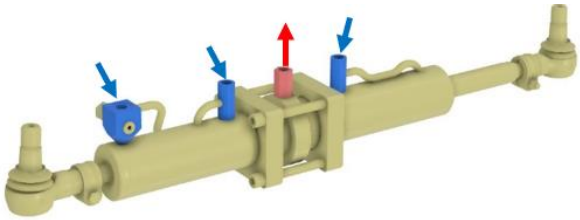

Figure 6. Steering axle piston

Table 1. Connection line parts list

No	Connection Line Pipes/Hoses	Part Material	Part Length
1	Hose	1/2'' Hydraulic Hose	630 mm
2	Hose	1/2'' Hydraulic Hose	1490 mm
3	Hose	1/2'' Hydraulic Hose	1430 mm
4	Hose	1/2'' Hydraulic Hose	1590 mm
5	Pipe	E235+N Class Ø18 mm Steel Pipe	2057 mm
	Pipe	E235+N Class Ø18 mm Steel Pipe	1730 mm
	Hose	5/8'' Hydraulic Hose	800 mm
6	Hose	1/2'' Hydraulic Hose	385 mm
7	Hose	1/2'' Hydraulic Hose	470 mm
	Pipe	E235+N Class Ø15 mm Steel Pipe	1557 mm
	Pipe	E235+N Class Ø15 mm Steel Pipe	1550 mm
8	Hose	5/8'' Hydraulic Hose	855 mm
	Hose	5/8'' Hydraulic Hose	360 mm
9	Hose	Silicone Hose Ø18	275 mm
	Hose	3/4'' Hydraulic Hose	1400 mm
10	Hose	1/2'' Hydraulic Hose	715 mm
	Pipe	E235+N Class Ø15 mm Steel Pipe	1700 mm
	Pipe	E235+N Class Ø15 mm Steel Pipe	850 mm
	Hose	1/2'' Hydraulic Hose	420 mm

2.4.1. Steerable Axle Piston

On the piston on the steerable axle, there are 3 hydraulic oil inputs shown in blue in Figure 6 and 1 hydraulic oil outlet shown in red. These inputs allow the piston to move back and forth, allowing the additional axle to perform the steering task. The outlet sends the hydraulic oil back to the oil tank.

2.4.2. Hydraulic Unit

The hydraulic unit is the unit that provides control of the hydraulic oil. This unit provides the size and timing of the hydraulic oil that will enter the piston. In this unit, as seen in Figure 7, there are 2 inputs and 4 outputs. 3 of these outlets return to the hydraulic unit and 1 to the radiator. The inputs are from the oil tank and hydraulic accumulator.

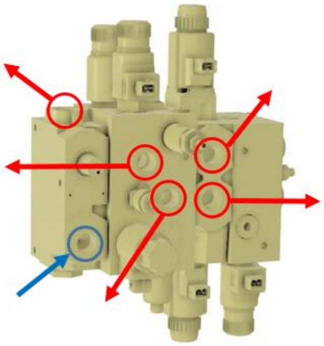

Figure 7. Hydraulic unit

Figure 8. Hydraulic accumulator

2.4.3. Hydraulic Accumulator

When there is a pressure drop in the system, it gives the hydraulic oil inside the system and ensures that the piston reaches the nominal state. As can be seen in Figure 8, there is a cover on which to put hydraulic oil and, if necessary, an outlet to supply hydraulic oil to the hydraulic unit.

2.4.4. Oil Filter

The oil filter ensures that the harmful particles in the hydraulic oil are filtered and prevents the harmful particles from damaging the system by preventing them from entering the system. As can be seen in Figure 9, there are input and output on the right and left. The hydraulic oil enters the oil filter after the pump and ensures that the hydraulic oil is filtered before reaching the hydraulic unit.

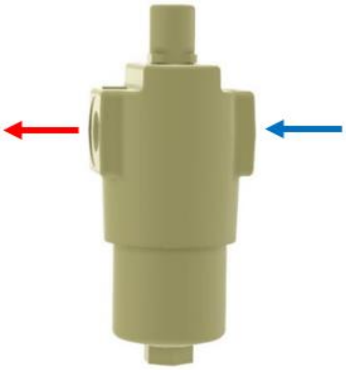

Figure 9. Oil filter

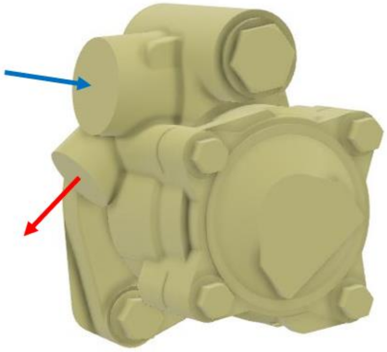

Figure 10. Pump

2.4.5. Pump

The pump is used to transport hydraulic oil over the system. The pump gets the power it needs through the motor. As can be seen in Figure 10, it has 1 input and 1 output. It ensures the circulation of hydraulic oil from the oil tank in the system.

2.4.6. Oil Tank

The oil tank is the part where hydraulic oil is stored and introduced into the system. As can be seen in Figure 11, there is a sensor on the oil tank that measures the level of the oil and informs the driver about the status of the hydraulic oil in the tank, a sensor that measures its temperature, and hose and pipe connections that provide inlets and output to the tank.

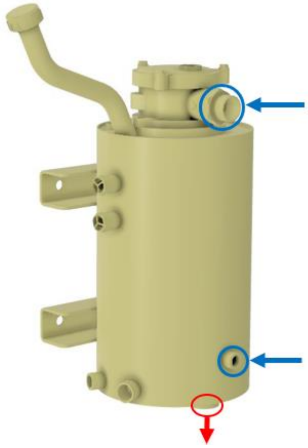

Figure 11. Oil tank

Figure 12. Radiator

2.4.7. Radiator

The radiator prevents the hydraulic oil in the system from overheating and keeps the hydraulic oil temperature at the desired level (65°-80°). As seen in Figure 12, it consists of 2 fans and 1 radiator. In order to provide the suction power needed by the radiator, a frame has been applied around it.

2.5 Measurements

In order to measure the oil temperature before and after the radiator integration, a sensor capable of measuring between -35°C and +140°C, with IP6K9K sealing feature, and a maximum deviation tolerance of ±0.5 °C was used. The sensor data related to the oil temperature were read in the vehicle control unit and transmitted to the 250 kbit/sec Can line, recorded and graphed using the vector device given in Figure 2.13 and the CanAlyzer program.

Figure 13. Device used for measurement records

A total of 6 tests were carried out at different times and under different conditions, 3 before the application and 3 after the application, and the improvement in the system was observed after the radiator was integrated. With the measurements taken from the temperature sensor integrated in the system oil tank (Figure 11), the oil temperature outputs were examined under different operating conditions. It was observed that the temperature increased up to 129-130 °C in 3 tests performed before the radiator integration. After the integration, when the oil temperature read from the temperature sensor reaches 80 °C, the radiator fans will be activated and the temperature will be reduced to 65 °C. Below are the results of the tests performed before the radiator application.

Within the scope of Test 1, 1300 seconds of observation were made at an average speed of 50 km/h. Although the initial temperature was 30 °C, the oil temperature reached 130 °C after 975 seconds. The oil temperature remained at 128-130 °C for the rest of the test. Test 2 was started at an initial temperature of 45°C at an average speed of 60 km/h. After 1350 seconds the oil temperature reached 130 °C. The oil temperature continued at 129-130 °C in the continuation of the test. Test 3 was started at an initial temperature of 41 °C and an average speed of 65 km/h. After 1650 seconds the oil temperature reached 129 °C. In the later stages of the test, the oil temperature continued at 126-129 °C. As a result of the tests, it was observed that the oil temperature reached 130 °C before integration and the temperature remained constant at these values. The results of the tests performed to keep the oil temperature within the target temperature range after the radiator application are given below.

Test 4, carried out at an average speed of 50 km/h, started at an oil temperature of 50 °C. The oil temperature reached 80 °C in 1100 seconds and was reduced to 65 °C in 350 seconds. In the following periods of the test, the oil temperature increased again to 80 °C after an average of 500 seconds and was decreased to 65 °C in 350 seconds. Test 5 was conducted at an average speed of 60 km/h. The test was also started at an oil temperature of 66 °C and after 500 seconds the oil temperature increased to 80 °C. With the activation of the radiator fans, the temperature was decreased to the target temperature of 65 °C. A total of 4 periods of testing were carried out and the oil temperature, which reached 80 °C in an average of 500 seconds, was reduced to 65 °C in 350 seconds. Test 6 was conducted at an average speed of 65 km/h. The oil temperature, which was 62 °C at the beginning of the test, reached 80 °C in 500 seconds. With the activation of the fans, the oil temperature was reduced to 65 °C in 350 seconds. In this test, the oil temperature reached 80 °C 3 times and was reduced to 65 °C.

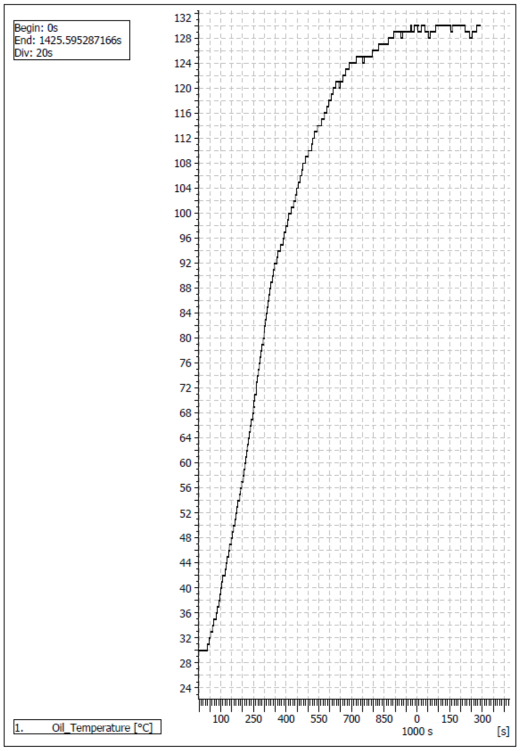

Figure 14. 1st test before integration

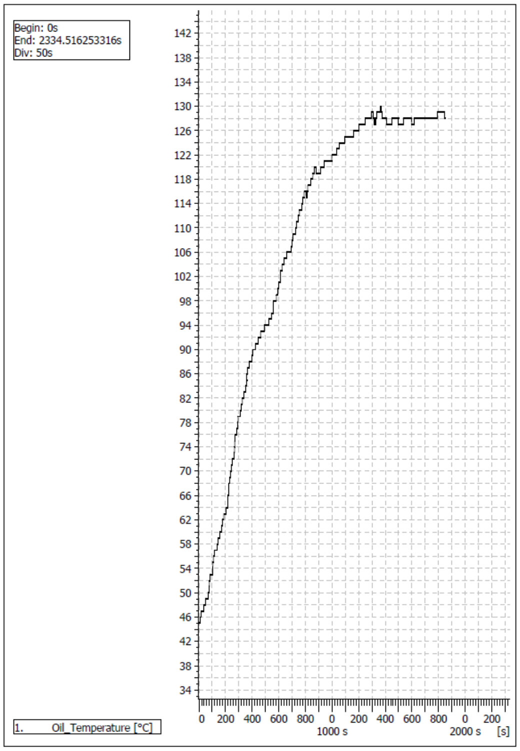

Figure 15. 2nd test before integration

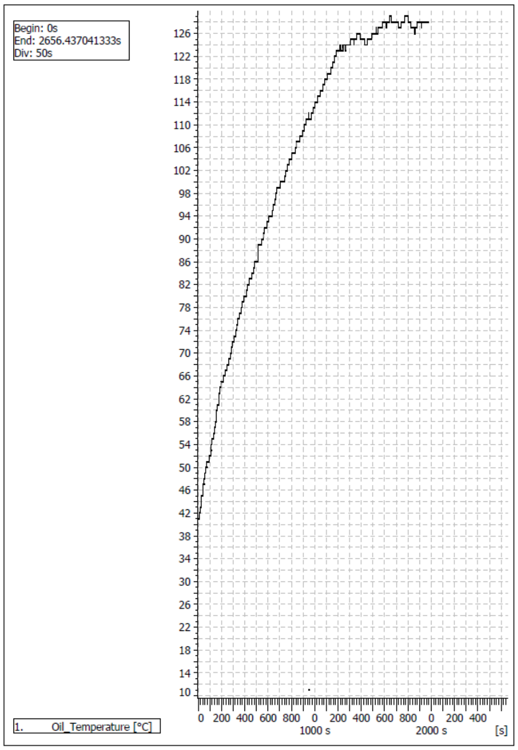

Figure 16. 3rd test before integration

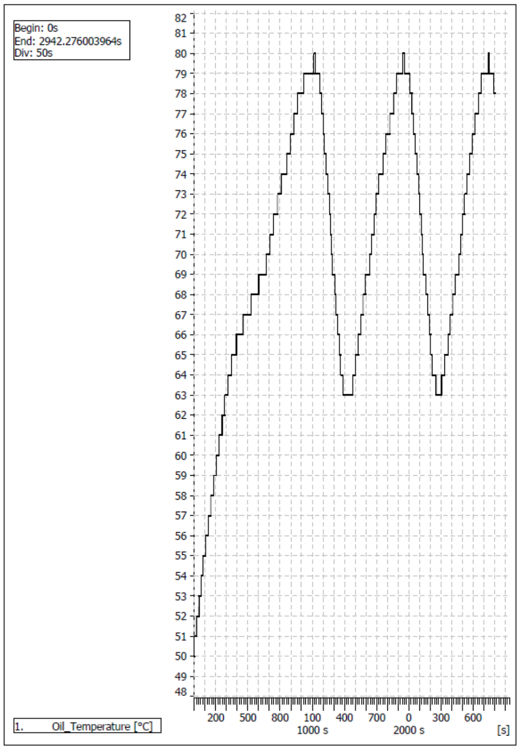

Figure 17. 4th test after integration

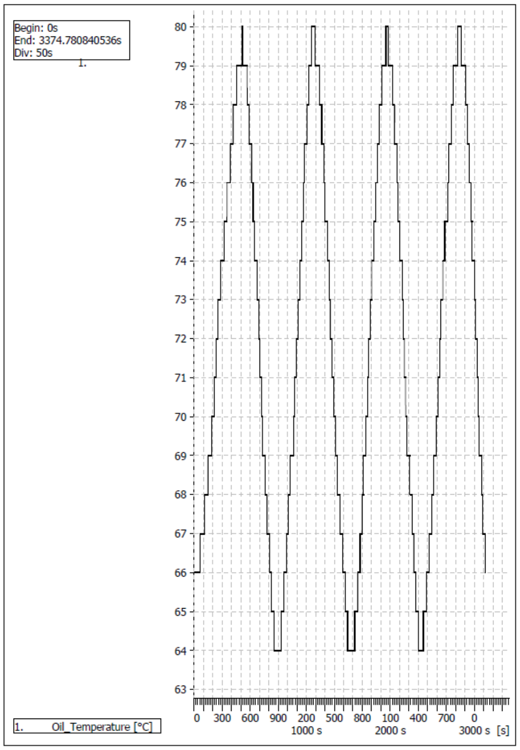

Figure 18. 5th test after integration

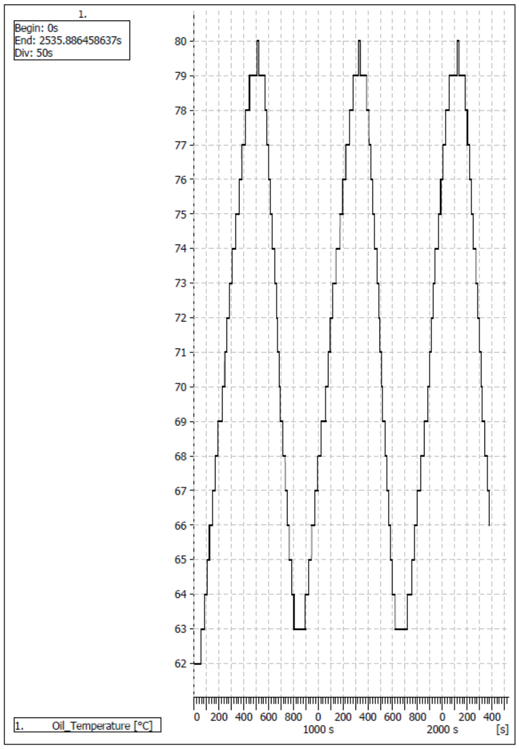

Figure 19. 6th test after integration

Table 2. Oil temperature condition in different conditions before and after radiator integration

Test Status	Tests	Average Vehicle Speed (km/h)	Ambient temperature (°C)	Test Time (seconds)	Maximum oil temperature (°C)
Before Integration	Test 1	50	28	1300	129
	Test 2	60	26	1750	130
	Test 3	65	30	1740	129
After Integration	Test 1	50	26	2850	80
	Test 2	60	29	3100	80
	Test 3	65	28	2380	80

As a result of the tests made after the integration, it has been observed that if the oil temperature reaches 80 °C, the radiator fans are activated and the temperature is decreased to 65 °C in an average of 350 seconds. Similar results were obtained in the tests performed at different operating temperatures and different vehicle speeds to observe the fan effects. The adequacy of the radiator application to reduce the rising oil temperature during operation was observed, and the oil temperature could be controlled independently of the air temperature and the operating conditions of the vehicle. According to the data obtained from different operating conditions according to Table 2, it has been seen that the temperature can be reduced to the desired values after integration.

3. Conclusion

In this study, conducted for the overheating problem of the hydraulic oil of the axles ruled by hydraulic pressure, radiator integration was made into the system in response to the overheating problem of the oil experienced on the 5th axle of the Akia 25 meter bus. The temperature values taken from the critical points on the system were noted and the frame design was realized for the radiator integration to work in the most effective way. As a result,

- The oil temperatures that pose a risk in the steerable additional axle are enabled to operate safely in the 65°-80° degree band with the currently developed system.
- Operation of hydraulic oil at desired temperatures (65°- 80°) ensures that the oil maintains effective viscosity.
- This problem has been avoided as the hydraulic oil overheating (130°) restricts the steering movement since the system is operating with pressure.
- Since the hydraulic oil overheats (130°) shortens the life of the oil, continuous service and labor costs are avoided.
- Overheating of the hydraulic oil (130°) restricts the movement of the axle, reducing the turning radius and reducing the control capability, this problem has been avoided.
- It brought an additional cost to the production cost of the bus, but considering the long-term maintenance, service and consumable costs, it was seen that it would provide a cost advantage.

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