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Research and Analysis of Cooling System for Diesel Locomotive

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ABSTRACT
With the continuous development of diesel locomotives in the direction of single power, the heat dissipation of the locomotive cooling system is getting bigger and bigger, and its performance directly affects the economy and reliability of the locomotive. Due to the limitation of locomotive axle load and structural space size, there is a great technical problem between the cooling system design and the arrangement of the cooling device and the overall layout of the locomotive. The increase in the number of radiators, making the number of cooling system processes are correspondingly increased, resulting in locomotive cooling system water resistance and water system pressure are greatly improved. The traditional cooling system form and the radiator structure are difficult to meet the development requirements of high power locomotive. Based on the conventional cooling system design method, a multi-process radiator is proposed. The multi-process cooling system has the advantages of high cooling efficiency, simple structure, small auxiliary power consumption of the pump and high reliability of the cooling system components. In this paper, the cooling system and its function, the existing cooling technology and the multi-process radiator are studied and analyzed, and the three-process radiator and the single-process radiator are tested and compared. In this paper, a new multi-process radiator structure scheme is proposed for the design requirements of CKD9 diesel locomotive cooling system. The program effectively uses the radiator cooling water and cooling air temperature difference, to achieve the purpose of increasing heat dissipation.

KEYWORDS: diesel locomotive; cooling system; radiator; process; contrast

1. Introduction

The cooling system is an important part of the diesel locomotive, which plays an important role in ensuring the normal and reliable operation of the diesel locomotive. Not only that, with the development of high-speed, heavy-duty high-power diesel locomotives, the cooling system is also important for improving the economy of locomotive operation.

For the cooling system of the diesel locomotive cooling system, especially for single-section high-power diesel locomotives, the following requirements should be made from the aspects of structure, energy consumption, process and operation:

(1) the cooling device is compact, small size, light weight, meet the serialization requirements;

(2) in the cooling room, the layout is reasonable, easy to install, disassemble, monitor and other equipment layout and crew convenience;

(3) manufacturing and maintenance of good technology, easy to use, low cost;

(4) as far as possible the use of ordinary metal and non-metallic materials, reduce non-ferrous metal consumption;

(5) in the diesel locomotive running under various climatic conditions, the cooling device should ensure that diesel engines, traction motors and other parts of the cooling system in the normal heat load state of reliable work;

(6) The cooling unit allows the diesel engine to operate at normal water temperatures so that the average actual fuel consumption and the cooling fan are minimized;

(7) For the cooling system of the traction motor of the diesel locomotive, the following points should be considered: the application of centralized or grouped air filtration and ventilation systems; the cooling air volume of the traction

motor can be adjusted with the load and the temperature change; Of the high efficiency of the fan; the use of air filter to ensure that the air cleanliness and reduce ventilation resistance;

(8) radiator air intake device should have good aerodynamic performance and reasonable structure;

(9) make full use of the space between the frame, set the traction motor strong air duct;

(10) so that the radiator from the diesel engine exhaust emissions of pollution;

(11) the use of aerodynamic performance and good heat transfer performance, and easy to 4 in the body layout of the efficient radiator;

(12) in the maintenance of stable performance under the conditions of high reliability and service life [1].

All of the above characteristics are in line with the following major economic requirements: the cooling system manufacturing and use costs should be reduced to a minimum. Therefore, it is necessary to carry out technical and economic analysis on the impact of various factors such as structure, power, process and application on the cost of manufacturing and using the cooling system in order to determine the further research tasks and directions when developing a diesel locomotive cooling device.

At present, the domestic diesel locomotive cooling water system is generally divided into high temperature system and low temperature system. Cooling devices are usually used in multiple sets, modular, interchangeable single-process radiator structure. The outstanding advantages of this structure are versatility, interchangeability, easy maintenance. For different power levels, different application environments and different technical requirements of diesel locomotives, generally can increase or decrease the number of radiators to meet their cooling capacity requirements. The drawback of the cooling system is the cooling efficiency of the radiator is not high, the locomotive water system resistance, high working pressure and poor system reliability.

With the continuous improvement of diesel locomotive power, requiring the cooling of the locomotive cooling system is getting bigger and bigger. Due to the limitation of the locomotive structure space and the axle load, it is impossible to meet the cooling capacity requirement of the locomotive simply by increasing the number of radiators. Therefore, it is necessary to put forward the requirement of the structure of the cooling system and the performance of the radiator, the device has high performance, lightweight and high reliability.

The multi-process radiator proposed in this paper is based on the conventional cooling system design method, in the radiator internal effective segmentation to achieve its structural design. And by greatly reducing the radiator water resistance and water system pressure, by rationally arranging the flow of cooling water from the multi-process radiator, increasing the average logarithmic temperature difference between the cooling water and the cooling air and improving the heat transfer performance of the radiator The

2. Locomotive cooling system

2.1. The role of the cooling system

The cooling system of the diesel engine itself is a combination of cooling airtight water, engine oil and supercharged air cooling equipment, which includes surface heat exchangers (radiators), fan units, air passages, shutters and heat sinks , Asked the heat exchanger (used to cool the diesel engine oil and pressurized air), circulating pump and pipeline composed of water, oil circulation system. Its role is as follows:

1. Effect of cooling on diesel engine power. Diesel engine work, the fuel contains a part of the heat (40%) into effective work, 20% -30% of the heat required by the cooling device to the atmosphere. With the increase in the power of diesel engines, cooling requirements of the cooling device should be a corresponding increase in the heat. Therefore, the problem of high-power diesel engine cooling is very prominent.

In addition the cooling water temperature is too low, the diesel engine power will decline. This is due to the low oil and water temperature will lead to oil viscosity increases, the friction loss increases. At the same time, the amount of heat lost by the cooling water also increases, resulting in an effective power drop. In short, the diesel engine cooling water and oil temperature should be kept within the normal range, the diesel can only work properly and reliably.

2. The need for pressurized air cooling. The temperature of the supercharged air of the diesel engine has a great impact on its economy and reliability. In order to increase the diesel engine power, or in the diesel engine power remains unchanged under the conditions, in order to reduce the thermal strength of diesel engine parts and reduce fuel consumption, are widely used in the case of diesel engine parts to maintain a certain heat conditions, This effective measure. At present, the world generally uses high pressure to improve the diesel engine single cylinder power. The average effective pressure of the four-stroke high-pressure diesel engine is around 2-2.3MPa. Generally speaking, the pressurized air temperature for each lower 10 °C, diesel engine power will increase 2% -3%.

3. Effect of cooling on working fluid of hydraulic drive. During the operation of the hydraulic transmission, the heat of the various losses causes the working oil temperature to rise. If the working oil is not cooled in time, the oil temperature will soon exceed the allowable range (110 °C). The greater the power input to the hydraulic drive, the more heat generated, the higher the cooling requirements of the cooling device. If the cooling capacity of the cooling device is insufficient, the input power of the transmission must also be limited by the allowable temperature rise of the working oil.

With the hydraulic brake of the diesel locomotive, the working oil of the liquid can be consumed in the stator and into heat, so that the oil temperature rise, and then in the oil-water heat exchanger to be cooled, so that the oil temperature maintained within the required range to complete The kinetic energy of the train into heat, and then distributed to the atmosphere by the radiator. If the cooling capacity of the cooling device is insufficient, the oil temperature will gradually rise until the permissible range is exceeded. Therefore, the size of the hydraulic braking power is also limited by the cooling capacity of the cooling device.

4. Effect of cooling on the operation of power transmission. In the power transmission diesel locomotive, a variety of AC and DC motors, rectifier power and size are determined by the continuous current and maximum voltage. The size of the continuous current is limited by the permissible temperature of the motor windings and rectifier components. High-power motors, electrical appliances are generally required to use a special ventilation device to cool to maintain the work in the allowed temperature [2].

2.2. Classification of cooling systems

Diesel locomotive cooling system, on the cooling of different ways, can be divided into ventilation cooling system, diesel water cooling system, pressurized air cooling system and various types of oil (oil, hydraulic transmission oil, etc.) cooling system. In addition to the ventilation system and air, the rest of the systems are associated with water. Therefore, the rest of the system can also be attributed to the water cooling system. Therefore, the internal combustion engine cooling system can be summarized as ventilation cooling system and water cooling system two types [3].

1, Ventilation cooling system: designed for cooling traction motors and electrical appliances and set. The system consists of fans, into the air duct and air filter device and so on. According to the structural characteristics of the ventilation system can do the following categories.

(1) according to the layout of the fan classification: from the ventilation, independent ventilation.

(2) according to the ventilation air import location classification: the car into the air, outside the car into the gas.

(3) according to the ventilation system of the supply of wind classification: single, centralized, mixed.

2, Water cooling system: including radiators, intercoolers, all kinds of oil and water heat exchangers, pumps, expansion tanks, cooling fans, hot air pipe and instrumentation. In addition to ensuring that the diesel and hydraulic transmission equipment to get the necessary cooling, in the winter to the diesel engine and the various parts of the preheat, and to the driver room to provide heating conditions. Classification of structural characteristics of water cooling systems are:

(1) by circulating water sub-road: independent circulating water system, single-cycle waterway system and double circulating water system.

(2) according to the water temperature adjustment system points: non-adjustable, limited regulation and automatic adjustment.

(3) closed by the water system points: open, closed.

2.3. The main components of the cooling system

Radiator

Radiator is one of the important components of diesel locomotive. He used to cool the diesel engine cooling water and oil, hydraulic transmission oil cooling water. The radiator should ensure that the temperature of the water and other cooled media is maintained within a certain range so that the diesel engine and other devices can operate normally regardless of the ambient temperature conditions [4].

Radiators are used in diesel locomotives in many different configurations: for example: Tubular, reinforced tube, tube, plate fin (aluminum) and double flow path radiator.

Oil-water heat exchangers

In order to maintain the normal working temperature of diesel engine oil, in the diesel locomotive on the use of oil-water heat exchanger, with cooling water to cool the oil. In the hydraulic drive diesel locomotive, also use water to cool the transmission work oil.

3. Cooling system design

3.1. Several existing cooling technologies

In recent years, domestic and foreign research on the cooling technology of diesel locomotives has made great progress and achieved great results, such as dual-channel radiator cooling technology, radiator dry cooling system and high temperature cooling [5]. Several cooling techniques are listed below:

Conventional cooling technology

In the design of the locomotive cooling system, in order to keep the cooling water flow rate through a radiator within a reasonable range, the radiator of the whole locomotive is usually divided according to the different locomotive cooling water circuit, Flow and intermediate piping in series or parallel connection, the locomotive cooling system is divided into multiple water processes. With the continuous improvement of diesel power and the increase of the number of cooling devices, the number of cooling system processes is increased, especially in low temperature cooling water system. To DF4D and DFll locomotive, for example, these two locomotives cooling system are using four water processes. The increase in the number of cooling system processes resulted in a significant increase in the water resistance of the locomotive cooling system and the water system pressure. The increase in pump outlet pressure not only increases the auxiliary power consumption of the locomotive pump, but also reduces the reliability of the working parts of the cooling system. In addition, as the number of processes increases, the water temperature through the radiator will be lower and lower , The temperature difference between the cooling water and the cooling air becomes smaller and smaller, so that the heat dissipated by the radiator is gradually reduced, and the cooling efficiency is gradually reduced. This makes the design of the locomotive cooling device more difficult.

two-channel cooling technology

Double-channel cooling technology, the so-called dual-channel radiator, is installed in a radiator with two relatively independent of the water chamber, that is, low-temperature water and high temperature water chamber. The low temperature water chamber is arranged on the windward side, and the high temperature water chamber is arranged on the leeward side. Low temperature cooling water and high temperature cooling water is cooled by the same cooling air. According to the radiator heat transfer mechanism, the radiator heat dissipation Q is determined by the heat transfer coefficient K, the cooling area F and the average temperature difference Δt of the two fluids,

$$Q = K \cdot F \cdot \Delta t$$

Increasing the heat dissipation Q can increase the heat transfer coefficient K, increase the heat dissipation area F and increase the average logarithmic temperature difference Δt. Taking effective measures to significantly improve the heat dissipation factor on the air side of the heat sink is the key to improving the heat transfer coefficient of the radiator. On the current level of thermal fin research, air side of the heat release coefficient has reached a high level. Increase the cooling area F will increase the fin distance and fin depth, but the fin distance and fin depth has a best application range, cannot be arbitrarily reduced or increased. As for the increase in the number of heat sinks, but also by the locomotive structure size and weight limit. In terms of diesel locomotive cooling system, the water temperature of the high and low temperature system and the outside air temperature are determined by the working conditions of the diesel engine and the locomotive. So the radiator cooling water and the logarithmic temperature difference Δt is basically determined. With the increase in the depth of the radiator, the more to the radiator on the side, the cooling water and cooling air temperature difference is smaller, the greater the cooling air through the radiator, the greater the heat transfer less. As the dual-channel radiator will be placed in the high-temperature water on the leeward side, which effectively improve the radiator cooling water and cooling air temperature difference between the radiator to improve the heat transfer, so that the cooling capacity of the radiator to be sufficient Use, which is the dual-channel radiator to improve the cooling capacity of the mechanism [6].

High temperature cooling technology

High temperature cooling technology, the so-called high temperature cooling is by increasing the diesel engine cooling medium (cooling water or oil) temperature, to increase the cooling medium and the ambient air temperature difference between the locomotive cooling device to improve the cooling capacity, at the same time, Cylinder temperature is reduced, reducing the heat loss of the diesel engine, improving the economy of the diesel engine. At present, the domestic motorcycle common cooling water temperature is generally not more than 88 ℃. According to the experiment confirmed that the diesel engine often in the subcooled state (cooling water temperature at 40 ~ 50 ℃) operation, the parts wear than the normal working temperature (80 ~ 90 ℃) when running several times, from the reduction Cylinder corrosion, wear and improve fuel economy point of view, the best temperature of the diesel engine should be 120 ~ 140 ℃ or so, this can reduce the mechanical loss, save fuel, improve the part of the load is the combustion performance and improve efficiency. At the same time, due to the improvement of the cooling water temperature, in the air mass flow, temperature, radiator structure under the same conditions, through the radiator heat greatly increased. Conventional locomotive cooling system expansion tank is the atmosphere, known as the semi-open cycle system. As the altitude of more than 3000m at an atmospheric pressure, the water temperature will rise at 88 ℃. As a result, many modern locomotives have designed the cooling water system as a closed system, and by increasing the boiling point of the cooling water by means of a system pressurization method. According to the calculation, at a standard atmospheric pressure, the system pressure 0.05MPa, water boiling point of 112 ℃, if the locomotive at an altitude of 3000m altitude, the pressure of 0.05MPa side of the water boiling point of 105 ℃. Therefore, the pressure is conducive to high temperature cooling technology. In summary, this is the mechanism of high-temperature cooling technology to improve the cooling capacity.

Dry cooling technology

Dry cooling: the so-called dry cooling is in the locomotive diesel engine and cooling water temperature is relatively low, the cooling water does not enter the radiator and all back to the ad hoc water tank, or stored in the diesel engine and low temperature cooling system tube In the middle of the road. When the cooling water temperature rises to the set temperature, the cooling water enters the radiator. Dry cooling system is still divided into two separate low and low temperature cooling water to properly improve the cooling water temperature, thereby improving the system cooling capacity. Dry cooling water system features:

(1) has an effective ability to prevent cold. As the diesel engine does not work or oil, water temperature is low when there is no cooling water in the radiator, which can more effectively prevent the radiator freezing and cooling water, so that the diesel cooling water temperature is always maintained within the appropriate range.

(2) cooling fan with pressure-type arrangement. Compared with the suction type, the pressure-type cooling fan is sucked in the air temperature is low, the density is large. At the same volumetric flow, there is a greater air mass flow rate than the inhaled winds, and thus the same heat dissipation is less power.

(3) dry cooling water system is generally pressurized cooling, which can improve the altitude of the cooling water boiling point. Both with the work of diesel engines and cooling systems, but also reduce the consumption of cooling water.

(4) As the radiator was placed in the sub-top of the auxiliary, so the lower side of the larger space can be arranged other parts, is conducive to the overall design of the locomotive and auxiliary system transmission.

(5) cooling fan with auxiliary AC variable pole motor drive, compared with the traditional hydrostatic, coupling device is easier, more convenient, and not affected by the cold climate [7].

4. Research on Multi-process Radiator

4.1. Structure of the proposed program

With the continuous improvement of diesel locomotive power, requiring the cooling of the locomotive cooling system is getting bigger and bigger. Due to the limitation of the locomotive structure space and the axle load, it is impossible to meet the cooling capacity requirement of the locomotive simply by increasing the number of radiators. Therefore, it is necessary to put forward the requirement of the structure of the cooling system and the performance of the radiator. The device has high performance, lightweight and high reliability. In order to meet the needs of the current locomotive market, based on the existing diesel locomotive cooling technology and radiator manufacturing technology, to further improve the cooling capacity of the locomotive cooling system, improve system reliability and reduce energy consumption in the conduct with the detailed study, and put forward the idea of the structural scheme of multi-process radiator of locomotive.

Improve the cooling capacity of the radiator, mainly by increasing the radiator heat transfer area, improve the radiator heat transfer coefficient and improve the radiator cooling medium to achieve the average logarithmic temperature difference. The multi-process radiator proposed in this paper divides the radiator along the depth direction (the direction of flow of the cooling air) into two sequential and two or more processes. Through the rational arrangement of the cooling air and the cooling direction and flow order of the cooling water of the same cooling system, it is possible to make more efficient use of the temperature difference between the hot and cold medium, improve the radiator unit mass and the heat volume per unit volume to improve the cooling efficiency of the cooling system The purpose of [8].

Double-channel radiator cooling technology, Dalian Diesel Locomotive Research Institute developed a new technology for diesel locomotive cooling device, in 1994 by the Ministry of Railways Locomotive and Rolling Stock Industry Corporation identification. The heatsink was installed in ND2 Type 191 and 037 locomotives in March 1987 and September 1989, respectively, in October 1990 and April 1991 in Dongfeng 9 type 0001 and 0002 locomotives, 1992 In November and June 1993, the two-channel radiator was installed on Dongfeng 11 type 0001 and 0002 locomotives. Bench test, water resistance test and practical application show that the two-channel radiator cooling technology to improve the radiator cooling capacity, reduce the length of the cooling device and reduce the cost of cooling equipment has a significant effect. Ziyang Diesel Locomotive Works, Dalian Diesel Locomotive Research Institute and other radiator manufacturers and units are using this new technology [9].

Multi-process radiator itself is the same radiator to achieve the cooling water system, the total number of processes. As a result, the conventional cooling system relies on the locomotive head and the different piping connections to realize the drawbacks of the water system process. For example, the circulation of the cooling water is too long, the water resistance increases and the pump outlet pressure is high.

In order to facilitate the description of multi-process radiator can effectively improve the logarithmic average temperature difference basis, we selected the three-process radiator and three series of single-process radiator performance test results, the use of heat transfer NUT method, respectively Calculate the heat dissipation of the two cooling system equivalent units.

Order items 3 series single flow radiator 3 parallel three processes

No. 1 process second flow third flow radiator

1 air flow rate / kg · (s · m2) -1 10 10 10 10

2 water flow / m3 · h-1 12.36 12.36 12.36 12.36

3 Number of heat sinks 1 1 1 3

4 water flow rate / m · s-1 1 1 1 1

5 Heat transfer coefficient / kw · (m2 · k) -1 0.100 0.100 0.100 0.113

6 Intake air temperature / 40 40 40 40

7 Water temperature / 78 75.21 72.63 78

Calculation of heat dissipation / kw 39.01 36.15 33.49 39.80

Total heat dissipation / kw 108.56 39.80 × 3 = 117.78

As can be seen from Table 4-1, the total heat dissipation of the three parallel three-stage radiator standard samples is 117.78 kW, which is about 8% higher than the heat dissipation of the three parallel single-stage heat sinks of 108.56 kW.

In addition, according to the radiator bench test results show that the three-way radiator at a water speed of 1 m / s when the water resistance of 0.0175Mpa, single-stage radiator is 0.034Mpa. So the three-way radiator water resistance than the three series of single-process radiator about 3.83% reduction. Figure 4-3 and Figure 4-4 are schematic diagrams of two equivalent unit water processes.

4.2. New cooling system design method

For the design method of the conventional cooling system, the heat transfer performance of the locomotive cooling system is designed according to the design parameters of the locomotive cooling system and the bench test performance of the conventional radiator and the aerodynamic performance test results of the cooling fan. Calculation and cooling consumption power design calculations.

For the multi-process radiator cooling system design and calculation, the conventional design method cannot be directly applied. The main technical key is the determination of the heat transfer performance parameters of the multi-process radiator and the performance matching of the cooling system. For conventional heat sinks, the determination of its heat transfer performance parameters is usually done by relying on the test. But for multi-process radiator, there is no corresponding radiator professional test bench to be able to effectively test it, with the heat transfer theory is difficult to calculate the method is accurate. Therefore, the development of multi-process radiator is the key to first study and study a multi-process radiator cooling system design and calculation methods and radiator heat transfer performance parameters to determine the method. Due to the multi-process radiator structure is limited, the current radiator test bench equipment and test equipment level, cannot effectively test the radiator flow between the air temperature and water temperature values, and thus multi-process radiator flow The heat transfer coefficient cannot be calculated. How to calculate the heat transfer performance of multi-process radiator on the basis of the existing test equipment conditions is the key technical problem.

Through the analysis of the existing radiator bench test report and a large number of radiator heat transfer performance design results are compared: multi-process radiator and the same core structure of the single-stage radiator in the heat transfer performance exists There must be a certain connection.

The three-part radiator is not a three-process radiator because there is no factor in influencing the flow order of the fluid. Only through the calculation to illustrate the difference between the radiator calculation and the overall calculation of the difference and correlation calculated by comparison: Calculate the radiator heat transfer coefficient of the radiator overall radiator test heat transfer coefficient of about 3%.

4.3. Water resistance analysis and erosion corrosion

Radiator water resistance mainly by the radiator cooling pipe along the loss of h1 and the radiator inlet and outlet of the local loss of hm composition. Taking the three-process radiator standard sample and the conventional radiator as an example, the cooling water flow through the three-flow radiator is only a single process heat dissipation under the condition that the original inlet and outlet structure size is the same and the same radiator flow velocity is maintained 1/3 of the device. On the other hand, due to the use of a three-process radiator cooling system, the intermediate connection lines for the separation process are eliminated, shortening the cycle length of the cooling water in the locomotive cooling system, reducing the loss of the pipeline, The efficiency of the locomotive to reduce the auxiliary power consumption.

Scouring corrosion is a metal failure caused by high-speed movement between metal and corrosive fluid, which is the result of mechanical erosion and electrochemical corrosion. When the solid phase particles in the fluid when the composition of the so-called liquid / solid biphasic flow erosion corrosion, it is caused by petroleum, chemical, water and electricity, mining and hydrometallurgery industries such as a variety of pumps, valves, There is not a lot of damage to the important reason.

Erosion is a very complex process, the impact of many factors, summed up mainly including materials (metallurgy), environmental and fluid mechanics three aspects, in the past people through weightlessness experiments and the introduction of various fluid conditions electrochemical test technology on the first two The influence of the factors of the law has been more in-depth study, and then carried out the interaction of erosion and corrosion research, in order to reveal the essence of erosion corrosion. In contrast, the study of the influence of fluid mechanics is superficial. Thus, both the prediction of the erosion test results and the deep description of the erosion corrosion incentives are limited; the larger errors produced by the repeated tests are also more difficult to explain and control.

Hydrodynamic factors generally affect the erosion corrosion performance by changing the size of the scouring strength or the mass transfer process. The final parameters include: fluid flow, angle of attack, particle properties (species, hardness, particle concentration, particle size and distribution, particle shape, crusher density and surface roughness, etc.), fluid properties (viscosity density) 11].

High flow rate often cause serious erosion corrosion, many materials, media systems, especially with the film material is often a critical speed, more than this fluid will cause a sudden increase in material loss. Therefore, the critical speed for engineering design is undoubtedly very important. This paper presents a multi-process radiator under the same locomotive operating conditions. Due to the fluid properties of the cooling water system of the locomotive, the nature of the particles, the material of the radiator and the environment of the radiator can be regarded as the same influencing factors. For this reason, the most influential factor of erosion corrosion is the fluid flow change. Similarly, the above three six radiator, for example, because the water through the radiator inlet has been reduced to single-process radiator 1/3, which will greatly reduce the radiator inlet water flow rate, both to change the fluid flow Can reduce the impact of cooling water on the end of the radiator tube, to avoid the water flow caused by sudden changes in the end of the radiator tube erosion damage, so multi-process radiator can improve the reliability and extend the service life.

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