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An Innovative Integrated Approach to Testing Motorcycle Drive Chain Lubricants

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An innovative integrated approach to the testing and comparison of motorcycle drive chain lubricants is presented. This is a novel way of testing the lubricant by using loaded operating chains and sprockets. A test rig has been designed to operate chains and sprockets in a clean environment and allow direct comparison between different lubricants. The advantage of this method over previous techniques is that it allows the differentiation of lubricants in a more controlled operating environment and evaluates the overall lubricant performance as opposed to individual properties.

The lubricants tested were a wax spray, PTFE spray and drip fed light oil. The test rig allowed measurement of the power saved by the lubricant in running the chains and sprockets. Chain length and component masses were also taken before and after running the chains and sprockets under load on the test rig. The results clearly show that any lubricant is preferable to none. The drip fed oil provided the greatest power saving and wear protection between the chain rollers and pins and the spray lubricants provided the highest level of protection between the rollers and sprockets.

1. INTRODUCTION

Chain drives offer lightweight, comparatively inexpensive and compact power transmission from a power source to a driven source, in a robust and adaptable way. To do this effectively and economically they must be lubricated in a manner such that sprocket wear, chain stretch, and power loss are minimised. Research is currently carried out into lubricant types, chains, and sprockets, on an individual basis. However the operating system has not been researched as an integrated system including the lubricant. Motorcycle chains operate in a changeable harsh environment and are subjected to extreme forces and contamination by water, salt and road dirt. Achieving meaningful comparison of chain lubricant performance is therefore complex and requires a systems approach.

Component and lubricant manufacturers hold the majority of research into motorcycles, chains, sprockets and their lubrication. However, lubricant manufacturers do not test chains and sprockets for wear, and chain and sprocket manufacturers do not test the lubricants. Motorcycle manufacturers test chains and sprockets, but with light gear oil, in order to choose their chain and sprocket suppliers. Tests undertaken by motorcycle consumer

magazines and lubricant manufacturers are on specific properties of the lubricant, for example, fling resistance, water resistance and adhesion of road dirt.

This paper describes an integrated systems approach to the testing of motorcycle drive chain lubricants. The design of a test rig and the testing of the lubricants is presented. The influence of different chain lubricants upon power loss, friction, and wear of the chains and sprockets is discussed and shows that this integrated system can define the strengths and weaknesses of each lubricant, differentiating between them.

2. BACKGROUND

2.1. Chains

Chain drives are amongst the oldest of the basic machine elements. The earliest reported applications appear to be in the drive mechanism for bucket elevators, such as the one attributed to Philo in 225 B.C.[1]. The invention of chains is often attributed to Leonardo Da Vinci as sketches of chains, that are remarkably similar in appearance to modern chains, appear in his Madrid Manuscript I at the end of the fifteenth Century [2]. In spite of

their widespread use, Freudenstein observed in 1984 that little research had been undertaken and they were not well understood. This observation, coupled with the desire of the automotive industry to reduce development time, has led to an increase in both theoretical and experimental research [3]. Studies include those by Wang *et al.* [4, 5], Kim [6] and Johnson [7, 8], Conwell [9, 10], Chen, Veikos and Freudenstein [11, 12]. In 1989, Conwell [9] detailed a brief history of chain drives and their important practical developments, noting that the first report in an ASME journal, devoted to the study of roller chain behaviour, was by Barlett [13] in 1935. Most modern work can be directly traced to Binder's [14] text, written in 1956, in which he both documented and extended the work of many earlier chain investigators.

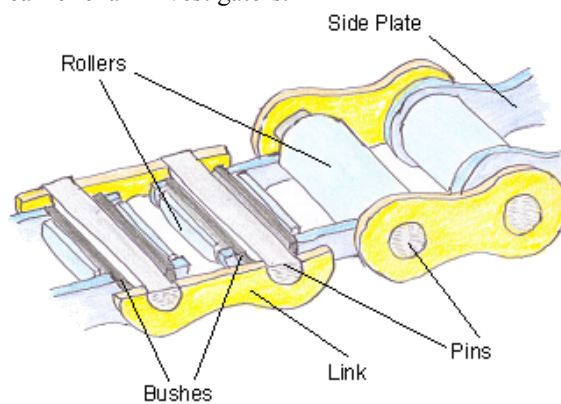


Figure 1. Chain schematic

Chain drives were first patented by Hans Renold in 1880 [15, 16] and first used by J.K. Starley in his rear wheel drive 'safety bicycle' [17] in the early 1900s. They offer lightweight, non-slip and comparatively inexpensive and compact power transmission from a power source to a driven source, in a robust and adaptable way [15]. To do this effectively they are made from materials that can withstand the tensile forces and loads experienced by the chain links. These links may be made from plastics or metals but, in the context of power transmissions, steel is most commonly used.

The dynamic chain load distributions and associated theory required to better understand these have been studied by Naji [18], Troedsson [19] and Ariaratnam [20]. Roller chains can have comparable efficiencies to gears: chains using pressurised oil lubricants can reach efficiencies of 99.7% [21].

Major improvements in chains began in the 1960s when the oilite bushed chain was marketed, Figure 1, followed by O-ring chains in 1970 and X-ring chains in 1999. Other improvements include the use of different materials and finishes such as alloy steel side plates, nitrile O-rings and high carbon alloy steel bearing pins. The use of computer modelling and finite element analysis is also now used.

2.2. Sprockets

A marked improvement in motorcycle sprockets has also been made in recent years. Research has been undertaken by Kim and Johnson [7, 8] and Uchaev [22] into sprocket profiles for improved chain-sprocket contact. Other improvements include machining methods, the use of aluminium and the addition of grooves on the sprocket teeth. In 2001 a new set of sprockets was released onto the market that utilised all these advances. The driving sprocket was machined in steel with a diamond cutter, which work hardens the steel and enhances the durability. Slight ridges on the tooth face were incorporated where it makes contact with the chain rollers, with the aim of trapping lubricant between the rollers and tooth face. The rear sprocket was Computer Numerically Controlled (CNC) machined from 7075 aerospace aluminium, and was the first commercially available sprocket with a profile designed to transmit power in only one rotational direction.

2.3. Lubrication

There is very little research available in the public domain regarding lubrication of chains, specifically in relation to motorcycle chains and sprockets. The Tribology Handbook [23] states that drive chains operating at speeds comparable to those of motorcycles should be used in conjunction with an oil bath. This is impractical on modern motorcycles. Two distinct types of aftermarket lubricants are available for motorcycle chains. These are spray on lubricants, which may contain wax or PTFE, and oil drip feed systems, that use light oil. Consumer motorcycle magazines [24, 25] undertake the majority of the available research, and report tests on the varying range of lubricants available from manufacturers. These reports investigate particular properties of the lubricants; such as fling resistance, water resistance, the quantity of road dirt that becomes stuck to the

lubricant and the lubricants ability to protect components from corrosion. During the researching of this subject it has been found that lubricant manufacturers test their lubricants in a similar manner to motorcycle magazines, and that motorcycle manufacturers do not test lubricants; advising that their chains be lubricated with a light oil. This is unsatisfactory as it soon flies off the chain and sprocket, leaving no lubricant for the majority of the time it is in use.

2.4. Motorcycles

The drive of modern motorcycles to ever increasing power outputs increases the demands on chains, sprockets, and lubricants. A modern sports bike in first gear may develop 340N of tension on a chain. The load bearing area on the drive pin is in the region of 400mm² in circular contact, giving a pressure of around 0.85N per mm². If the motorcycle travels at 100mph using a 254mm diameter rear sprocket, the chain is subjected to 333 times the force of gravity as it travels around the sprocket. Under these conditions a single chain link of 30g can have an effective mass of 10kg and it is this inertia that flings the lubricant off the chain.

The operating environment of the motorcycle is also harsh. The chain, sprockets and lubricant will experience water, salt and road dirt. The lubricant must keep the components lubricated whilst not mixing with road dirt and thereby becoming a grinding paste and accelerating component wear.

3. EXPERIMENTAL METHOD

3.1. Introduction

The testing was carried out in a laboratory on a test rig as opposed to on a motorcycle. This allowed controlled and repeatable conditions between tests.

6mm pitch chains and sprockets were chosen for this work. This size allowed a stylus of the surface profilometer to access the sprocket tooth surfaces, whilst permitting rig manufacture within reasonable time and budget constraints. Steel (En202) sprockets and chains were chosen which were representative of the steel chains and sprockets used on motorcycles. Non 'O'-ring chains were used so that the manufacturers lubricant within the chain would not affect the results.

The details of a 500cc motorcycle were taken and scaled, where necessary, to the 6mm pitch chains used. The driven sprocket consisted of 42 teeth, the driving sprocket of 16 teeth and the chain had 104 links.

Two spray-on lubricants, one wax and one PTFE, and a light drip fed oil were chosen as the test lubricants: these being the most commonly used after-market lubricants. One set of chain and sprockets were run without any lubrication as a benchmark for comparison.

The wax spray-on lubricant contained a hydrocarbon solvent carrier fluid. This solvent evaporated, leaving a layer of wax on the components. The PTFE spray-on lubricant

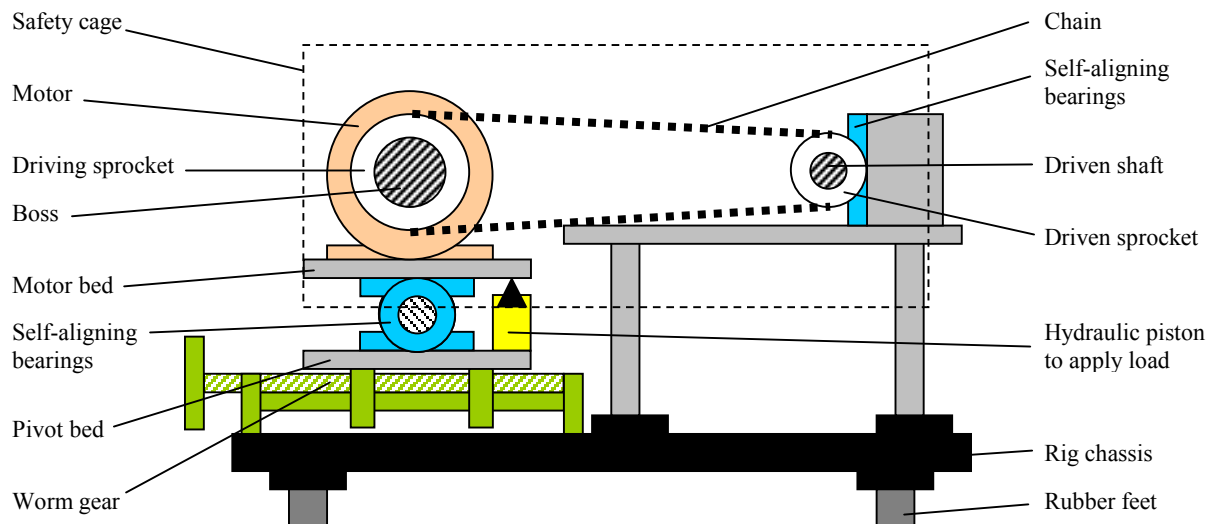


Figure 2. Test rig schematic

contained PTFE, zinc oxide and titanium dioxide mixed with a calcium based grease and the same hydrocarbon solvent carrier fluid. The drip fed light oil had a Viscosity Index of 110 with Kinematic viscosities of 66.2 cSt at 40°C and 8.95 cSt at 100°C.

3.2. Rig design

The test rig shown in Figure 2 was designed such that two sets of chains and sprockets could be operated simultaneously.

The rig was built on a steel chassis, isolated from the worktop by use of rubber feet. On the chassis were welded two separate sections; one to hold the motor and its adjustment with the driving sprocket, and another to hold the driven shaft and sprocket.

The motor was located on a bed with self-aligning bearings beneath. A shaft was passed through these bearings, and this allowed the motor and motor bed to pivot, altering the sprockets centre distance. A worm wheel was also fixed to the chassis, enabling alteration of the sprockets centre distance by moving the motor and motor bed laterally along the rig chassis, simplifying the fitting and removal of the chain.

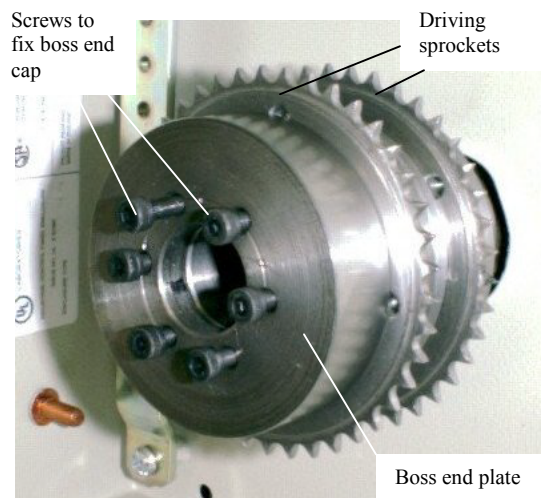


Figure 3. Boss and driving sprockets

The driven shaft was located such that the shaft centre height was the same as the motor shaft and a steel safety cage was fitted around the chains and sprockets, with a removable front to allow access.

The load was applied to the two chains by means of a hydraulically loaded piston. This applied a force to the edge of the motor bed, pivoting it around the shaft through the self-aligning bearings, thereby transmitting the load to the chains; each chain taking half the load applied.

A boss was manufactured, Figure 3, to locate the driving sprockets onto the motor shaft by use of a grub screw into a spline on the shaft. This boss allowed both circumferential and axial location of the driving sprockets on the motor shaft by use of an end plate on the boss and a pin through the sprockets. The pin holes in the sprockets were positioned such that the sprockets were held circumferentially one half tooth apart. This allowed the chains to be taut along different lengths; one along the top length and one along the bottom length, whilst remaining slack along their other lengths. This is representative of a motorcycle chain transmitting power.

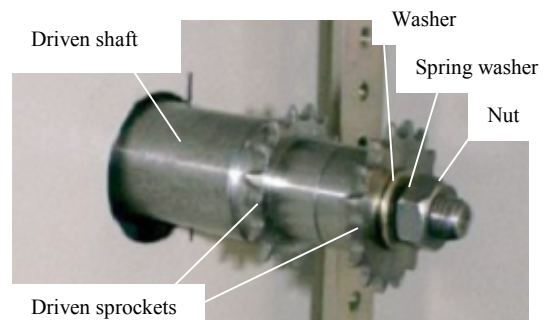


Figure 4. Driven shaft and sprockets

The driven shaft was designed such that the driven sprockets were placed onto it, the chain tension equalised and then the sprockets held firmly by a nut and spring washer, Figure 4.

A cross-contamination guard, with plates to catch the debris flung from the sprockets, was manufactured and located between the chain and sprocket sets.

Finally a motor speed controller was connected, along with a trip switch that would break the power supply should the chains break.

3.3. Testing

All components were cleaned in acetone in an ultrasonic bath to remove the manufacturers' protective coating. The chains, sprockets and four teeth on the 42-tooth sprocket were then identified

and marked using an engraver. The large sprockets were drilled for the boss pin and its fitting checked. Following this all components were weighed on digital scales, the tooth profiles taken using a Rank Taylor Hobson Form Talysurf Stylus profilometer and the chain length measured using a 3.5kg weight and a tape measure.

For the friction measurements each set of chains and sprockets were placed on the rig separately and the motor run at 785rpm with a load of 230N applied to the chain. This was calculated to be representative of a motorcycle running at a constant speed of 140mph overcoming drag and rolling resistance. The voltage and current were measured both before and after lubrication of the chain and sprockets and this was used to calculate the power saved by the lubricant.

For the main wear test the chains and sprockets were assembled and the tests run at the same speed and load as for the friction test. The chains were stopped, lubricated, and re-tensioned, if necessary, every 160mins, equivalent to 400 miles.

Testing of the first two sets of chains and sprockets, operated with the spray on lubricants, was terminated after 510mins, equivalent to 1180miles, due to the obvious wear on the sprockets and the need to retain sufficient sprocket tooth to obtain metrology data.

The same procedure was followed for the unlubricated and oil drip lubricated chain, and they were operated under the same conditions for the same periods of time.

At the end of each test the components were removed and cleaned with acetone in an ultrasonic bath. The acetone and wear debris was kept for analysis, the components weighed, chain length measured and metrology data taken for the 42-tooth sprocket.

4. RESULTS

4.1. Component mass loss

Table 1 and Figure 5 show the percentage component mass loss during testing of the chains and sprockets. The error bars allow for the accuracy of the scales ($\pm 0.01g$).

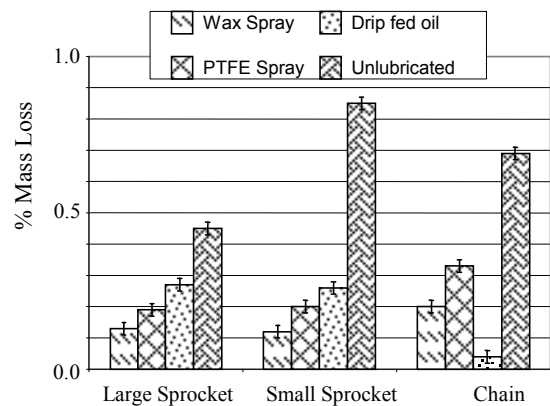


Figure 5. Component mass loss

Table 1
Component mass loss in grams $\pm 0.01g$

Lubricant	Component	Before Testing	After Testing	Mass Loss
Wax Spray	Large Sprocket	89.48	89.36	0.12
	Small Sprocket	32.73	32.69	0.04
	Chain	64.47	64.337	0.13
PTFE Spray	Large Sprocket	90.05	89.88	0.17
	Small Sprocket	32.74	32.68	0.06
	Chain	64.51	64.29	0.22
Oil drip feed	Large Sprocket	91.03	90.79	0.24
	Small Sprocket	32.52	32.43	0.09
	Chain	63.95	63.92	0.03
Unlubricated	Large Sprocket	88.99	88.59	0.40
	Small Sprocket	32.68	32.41	0.27
	Chain	63.94	63.50	0.44

Generally the sets of chains and sprockets show similar trends, the exception being the chain lubricated by drip fed oil. Being thinner than the spray on lubricants, and not designed to stick to the components, the oil will have become entrained between the chain pins and inner faces of the bushes. Protection in this area will have been minimal with the use of spray on lubricants. Being designed to stick to the components, these lubricants provided greater protection for the sprocket tooth/ chain roller interface.

4.2. Chain elongation

Table 2 and Figure 6 show the percentage chain elongation that occurred during testing for each chain. The error bars allow for the accuracy of the measurement ($\pm 0.5\text{mm}$).

Table 2

Chain elongation mm $\pm 0.5\text{mm}$

Lubricant	Before testing	After testing	Elongation
Wax Spray	622.5	623.5	1.0
PTFE Spray	622.5	623.5	1.0
Oil drip feed	622.5	623.0	0.5
Unlubricated	622.5	628.0	5.5

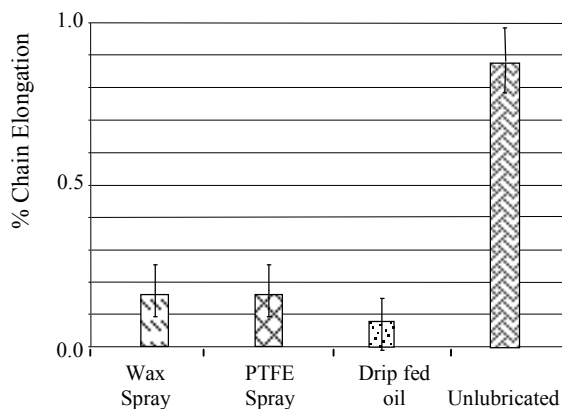


Figure 6. Percentage chain elongation

The results obtained indicate that the oil drip feed results in the least chain elongation. However, if the error bars are considered, it may be possible that the spray on lubricants result in the least elongation. The indicated results are likely to be correct as they correlate with the chain mass loss found. It would

be expected that lower mass loss would result in lower chain elongation due to reduced wear of the pins and bushes.

Motorcycle chains are usually replaced once they have extended between 2-3% of their original length. They also usually have O-rings fitted and would have the manufacturers lubricant between the pins and rollers. The choice of lubricant used by the motorcycle owner would, therefore, have little effect upon the chain elongation.

4.3. Power saved by lubricant

Table 3 and Figure 7 show the power saved by the lubricant in Watts over the unlubricated chain and sprockets. The error bars allow for the level of accuracy of the voltmeter and ammeter.

Table 3

Power used to operate chains and sprockets

Lubricant	Voltage Volts ± 0.01	Current Amps ± 0.01	Power Watts ± 0.75
Wax Spray	71.00	3.40	241.40
PTFE Spray	71.00	3.30	234.30
Oil drip feed	70.00	3.10	217.00
Unlubricated	72.00	3.60	259.20

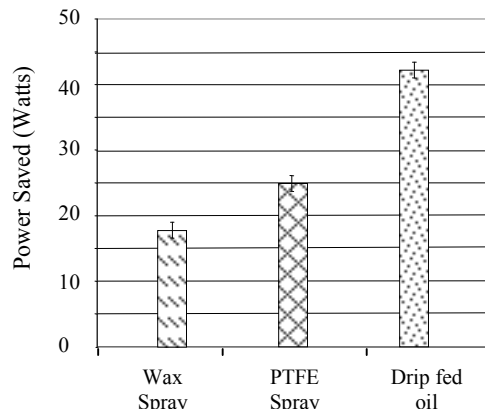


Figure 7. Power saved by lubricant versus unlubricated chain

The oil drip feed resulted in the greatest power saving over the unlubricated chain and sprockets. The power saved by the lubricant does not correlate with the mass loss for the sprockets. The lubricant formulation or the likelihood that most power is

absorbed not by the chain and sprocket contacts, but by the relative movement between the chain pins, bushes and rollers may explain these results.

4.4. Other results

The microscopy data for the chain links, sprocket tooth faces, and sprocket profiles were taken before and after testing in order to compare the lubricants ability to protect the surfaces. The wear debris from each set of chain and sprockets was also analysed.

The microscopy data obtained showed that the tooth surfaces became smooth during operation. This is likely to be due to plastic deformation caused by heating. The teeth also changed profile during the testing, due to the rolling of the chain rollers over the points of the teeth.

The wear debris analysis identified clear differences in the size and types of debris obtained between the unlubricated, oil drip fed and sprayed lubricants. The wax and PTFE spray exhibited similar sizes and types of wear debris. This data and further discussion is available in the full experimental write up [26].

5. DISCUSSION

The testing procedure enabled distinct results to be obtained from the different lubricants used with the sets of chains and sprockets. From the results it is possible to differentiate between the lubricants and specify their advantages and disadvantages for motorcycle drive chain lubrication.

Operating temperatures of between 100°C and 105°C, as opposed to the usual chain and sprocket operating temperatures of 50°C to 60°C, were found during testing. This caused some undesirable effects. The tests were not run for the expected 5186 minutes (effective 12,000miles) due to increased wear and plastic deformation. Had they been run for the time length intended, there would have been no teeth left from which to obtain results. This increased temperature was attributed to the safety cage restricting airflow, and the lack of aerodynamic cooling that occurs on a motorcycle. In possible future tests a fan will be fitted with an open wire mesh front on the safety cage.

When the protective cover was removed from the safety cage, a decrease in voltage output from the motor voltage recorder was noted. This

signified a drop in motor speed, suggesting that the friction and power loss increased. The removal of the cover would have allowed cooler air to circulate around the chains and sprockets, reducing their operating temperature. The increase in friction is likely to have been due to an increase in wear resulting from the material experiencing less plastic deformation.

The mass loss experienced by the oil drip fed chain may well have been reduced further had the chains operated at the anticipated lower temperatures. The lower operating temperature would have allowed a thicker oil viscosity and corresponding increase in film thickness, reducing the frequency of surface contacts. However this increased viscosity would be likely to reduce the power saved by this lubricant.

6. CONCLUSIONS

In the clean environment and temperature at which these non O-ring chains were operated:

- Any lubricant was preferable to none
- Oil drip feed provided the greatest wear protection between chain roller and pin
- Spray on wax or PTFE provided the greatest wear protection between chain roller and sprocket
- Oil drip feed provided the greatest power saving over unlubricated chains and sprockets

These conclusions may alter if the operating temperature was reduced, O-ring chains were used and/or water, salt and road grit introduced.

In summary this paper has shown that this integrated approach to testing allows clear differentiation between drive chain lubricants. Its development will allow the testing of new and current lubricants for both road and track bikes with both O-ring and non O-ring chains.

Once developed it will also be possible to test different chains and different sprockets with the same lubricant, allowing differentiation between these components and assisting motorcycle manufacturers with their choice of original equipment.

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