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NTRODUCTION

Today's familiar depth-type by-pass ilters* have been widely used on heavy uty highway, construction, and industrial iesel engines since the mid-1930's. Over he years, full flow filtration has been mproved with such filter media as the loth bag and pleated paper, but the by-ass filter has remained an unchanged part f the filter system working in combination ith the full flow filter to provide ex-ended oil and filter life along with ncreased protection against wear.

Before the development of highly dis-ersant engine oils, the by-pass filter ade extended oil and filter changes pos-ible by absorbing sludge-forming com-ustion by-products. At that time, clear r clean oil was an indicator that the ilter was doing its job.

Today, under normal operating conditions, combustion by-products are suspended in the oil to be removed when the lubricant is drained. Therefore, the primary function of the by-pass and full flow filters is to remove the abrasive particles in the oil such as wear metals, sand, and dust. Test data have shown that even with highly disperant oil, these wear producing abrasive particles are not in a finely dispersed, non-filterable form, but are quickly and effectively removed by the filters(1)**.

*Note: The canister-type by-pass filter used today is commonly known as the 750 and will be referred to as such in the remaining test.

**Numbers in parentheses designates References at end of paper.

BSTRACT

Engine tests were conducted to de-ermine the effects of various full flow nd by-pass lube oil filter combinations on iesel engine wear. The filter performance as determined by measuring the wear of iston rings, main and rod bearings in a ummins NTC-335, after contaminating the ube system with a known amount of AC Fine ust to accelerate wear.

The results of these tests prove:

1. It is possible to dramatically reduce the size of the by-pass filter through the use of stacked discs filter technology.

2. No sacrifice of engine protection or filter life is necessary.

3. By-pass filters extend engine life through improved filtration and reduced wear providing the lowest total cost to the engine user.

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The optimum absolute retention rating for a full flow filter is 40 micrometers. Tighter filter media would restrict oil flow. Therefore, the by-pass filter plays a critical role in removing those minute particles, 10 micrometers and less, which contribute most significantly to engine wear(2, 3). This is accomplished by directing only a small portion of the total oil flow, 7.57 liters or 2 gallons per minute, through the tighter by-pass filter media for finer filtration.

In recent years, there has been greater resistance by engine owners to use the by-pass filter because of increased oil and filter service cost, added weight of the housing, extra oil required to fill the housing, and service problems related to leaking covers, fittings, and gaskets. Therefore, a program was undertaken to research and test different filter media in an attempt to design a much smaller by-pass filter in a spin-on package. This spin-on filter would reduce the weight and size problem, provide easier access, foolproof servicing, and reduce labor, oil, and maintenance cost. A comparison of the spin-on and 750 is shown in Figure 1.

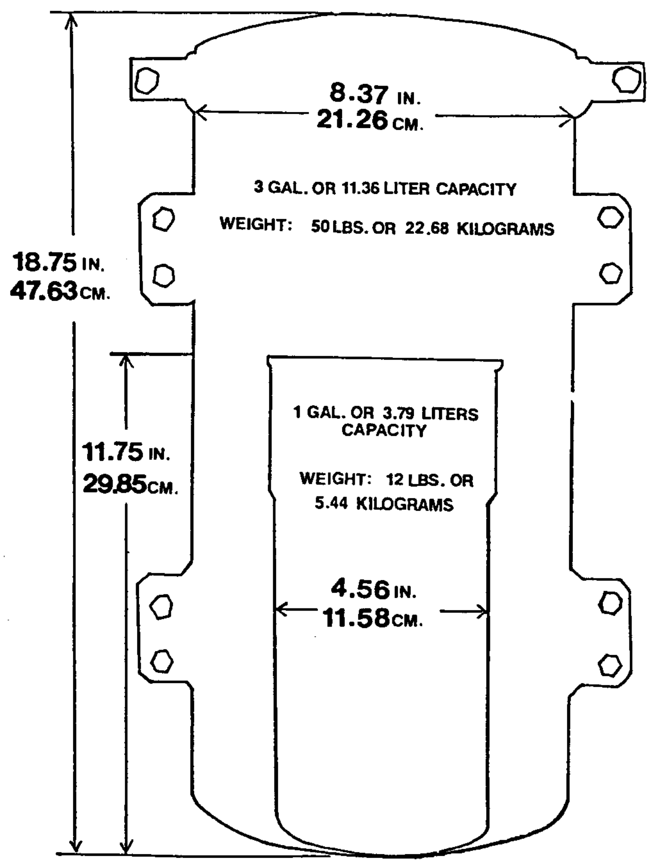

Fig. 1 - Dimension, volume, and weight comparison of old canister filter vs. new spin-on

The engine test program in this report was designed to measure different wear rates under accelerated conditions with the engines using various full flow and by-pass filter combinations. Experimental spin-on by-pass filters* were tested against the standard by-pass filter. Conclusions were based on the results of the wear test, along with a cost benefit analysis on a per mile basis of each alternative.

BENCH TEST

Over 200 laboratory bench tests were conducted measuring capacity and efficiency of various filter media. These tests produced only two filter designs, the pleated paper and the stack disc spin-ons, which could match the performance of the 750.

Two types of filter tests were used to screen prototypes. The first was a bench test designed to simulate extreme sludging conditions. In this test, the oil was circulated through the by-pass filter only, at approximately 7.57 liters or 2 gallons per minute. A plugging contaminant, soft C-2A, was added to the sump at a rate of 24.64 gms/hr. A constant inlet pressure of 345 kPa was maintained for 44 hours or until the test filter plugged. From the results shown in Figure 2, both the stacked disc and pleated paper SOBP filters were able to maintain life and sump contamination levels comparable to the 750.

The second type of bench testing involved a combination full flow and by-pass filter arrangement in which oil was pumped through the system at 106 liters or 28 gallons per minute. The oil flow was directed through the by-pass filter at 7.57 liters per minute. The contaminant, added to the sump at a rate of 1 1/2 gms. per hour, consisted of 1 gm. AC Fine Dust and .5 gms. Soft C-2A. The test was terminated when the differential pressure across the full flow filter reached 172.4 kPa (25 psid). Figure 3 compares data from three combination tests using the 750, the spin-on stacked disc, and the pleated paper SOBP filters. All three filter combinations had comparable life and acceptable contamination levels.

TEST SET UP AND PROCEDURES

The biggest deterrent of diesel engine testing of this type is the expense and time involved. We attempted to develop a

*Note: Spin-on by-pass will be abbreviated SOBP hereafter.

routine procedure to minimize human error. Testing was carried out on a 24 hour basis in one test cell. Three engines were used on a rotating basis to eliminate downtime between tests. As one engine was being tested, another was rebuilt to take its place as soon as the test was complete.

The three different engines used in this test program were all Cummins NTC-335's. Each engine was rebuilt according to Cummins Standard Procedure with special attention given to the rod bearings, main bearings, and piston rings. Various test operations such as weighing, assembly/disassembly were treated as identically as possible by laboratory standards.

The engines were installed in accordance with standard test cell procedures, which cover the instrumentation necessary to measure the basic parameters of engine performance, temperatures, and pressures. After installation and before beginning the test, the engine was given a four-hour run-in. An oil sample was then taken before the initial contaminant was added.

For the duration of each test, the engines were operated at rated speed and full load (2100 RPM and 1135 Newton meters). Normal operating conditions were maintained in each test with particular attention paid to oil sump, water, and air intake temperatures. Oil rifle pressure and engine blow-by were of significant importance since they vary as critical engines parts wear. Increasing blow-by pressure is an indication of ring wear, while decreasing oil rifle pressure signifies bearing wear. Four grams of AC Fine Dust were added to the engines every 4 hours and samples were taken ever 24 hours. The by-pass and full flow filters were changed every 52 hours and care was taken not to shut the engine

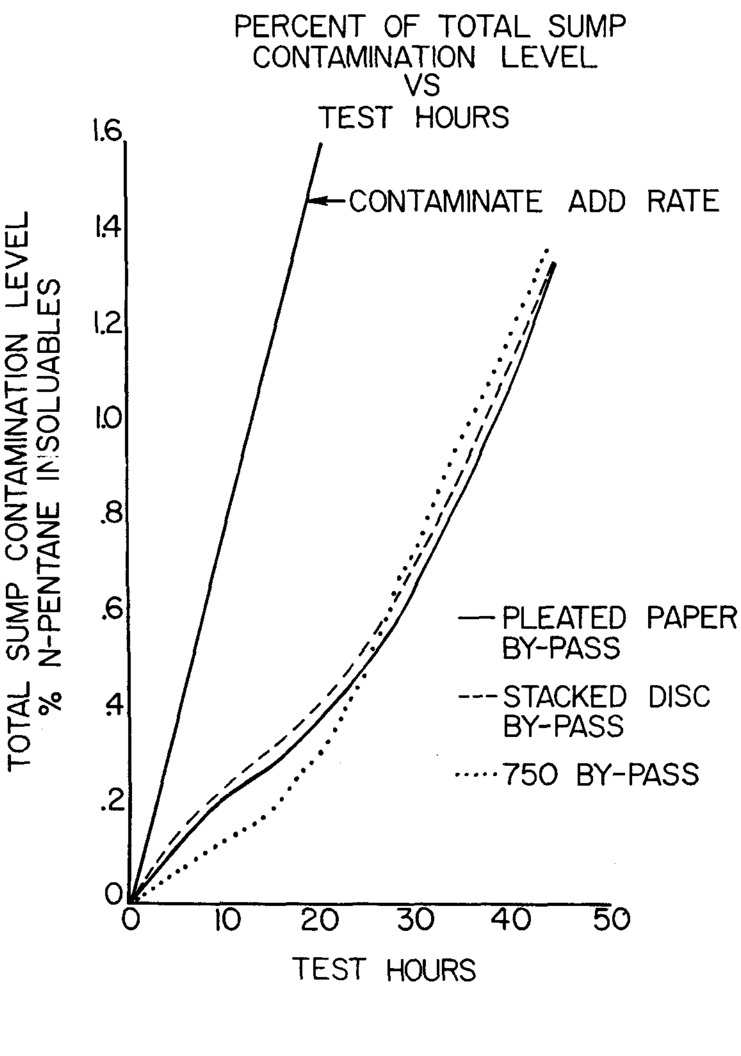

Fig. 2 - Bench test filter comparison of by-pass filters only

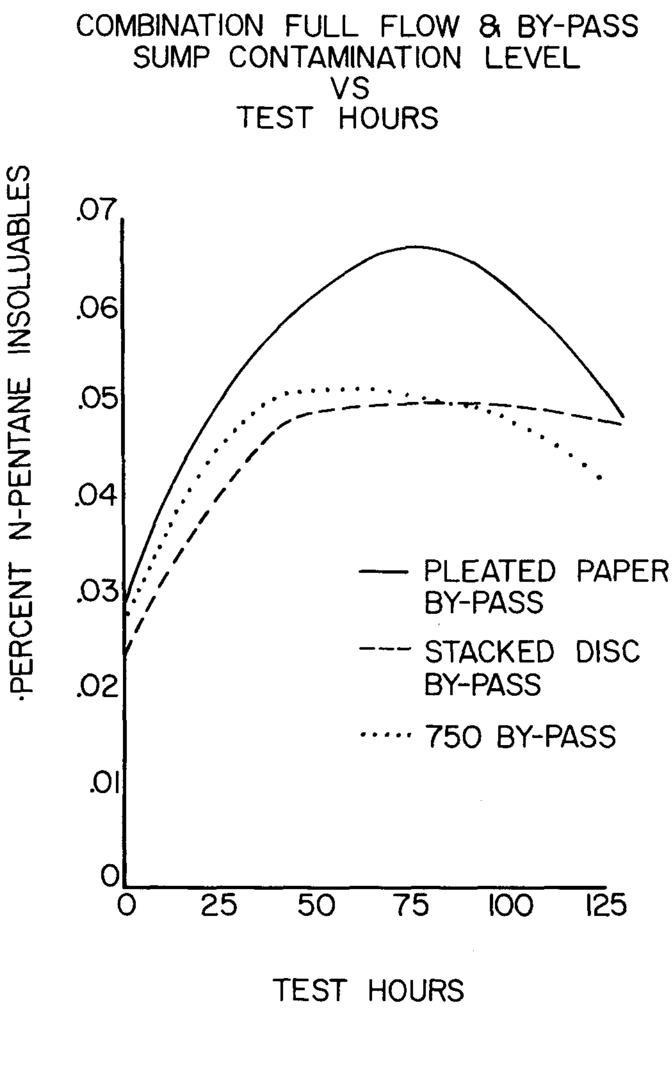

Fig. 3 - Bench test filter comparison of combined full flow and by-pass filter systems

down for more than 20 minutes when adding contaminants, taking oil samples, or changing filters. This was done to prevent contaminant settling. Runtime for each of the seven tests was 152 hours. A typical test cell is shown in Figure 4.

Due to the severity of the test, the turbocharger, injectors and cylinder heads were checked and rebuilt after each run. All other parts were inspected and replaced as necessary. Although the test engines were rebuilt according to standard Cummins NTC-335 specifications, used crankshafts were installed to avoid the long run in periods necessary to smooth the bearing surfaces.

The main and connecting rod bearings, the thrust bearings, the liners, and piston rings were replaced after each test. Wear was determined by weighing and measuring parts before and after each test.

The 750 housing holds nearly 11.36 liters (3 gallons) of oil when full. The SOBP filters hold only 3.79 liters (1 gallon) of oil resulting in a 7.57 (2 gallon) loss of capacity to the lube system. To compensate for the loss of oil capacity when testing the SOBP filters, a 7.57 liter (2 gallon) reservoir was installed between the oil pump and the by-pass filter. Six of the seven tests were run with 41.6 liter (11 gallons) of oil in the system and one test was run with 34 liters (9 gallons).

TEST CONDITIONS AND OBJECTIVES

This series of tests was designed to measure the performance of different lube filter combinations. The efficiency of the filters in removing contaminants from the oil was determined by measuring the sump's dust concentration level, and by measuring the amount of wear and weight loss on main bearings, rod bearings, and piston rings at the termination of each test. Filter change intervals were established by measuring differential pressure drop across the full flow filter to determine its plugging characteristics as dust was added to the engine sump.

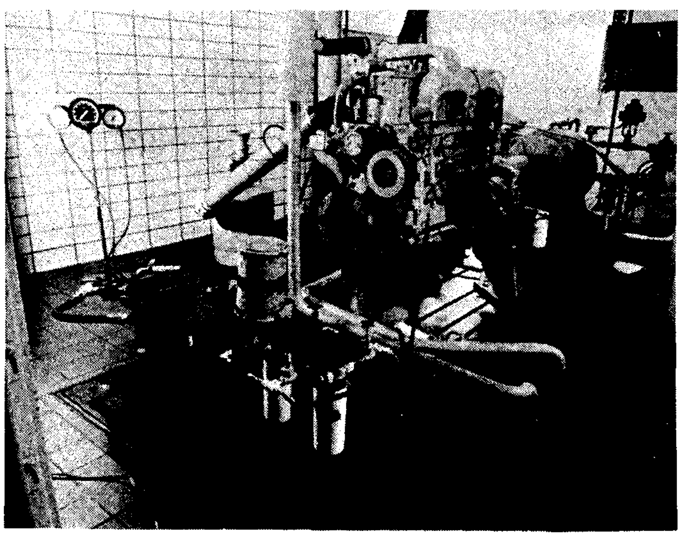

Fig. 4 - Wear test engine

Our objective was to differentiate the wear rate for each filter combination without completely wearing out the engine, since the typical practice among fleets is to rebuild engines prior to failure. With a dust add rate of 4 grams per 4 hours, these tests simulated an engine, equipped with a 99.9% efficient air filter, operating at full load and full speed in a dust storm with zero visibility. Under such conditions, we found that 152 hours was adequate test time to produce a discernable amount of wear.

Seven engine tests were conducted during this test program. The key variables considered in our analysis were: the effects of by-pass filtration, the effects of reduced oil capacity, differences in by-pass filters, and effects of accelerated wear. A description of each test and lube filter combination follow:

1. 40 Micrometer Full Flow/750 By-Pass - No dust was added in this test since we wanted to determine the amount of engine wear under clean operating conditions.

2. 40 Micrometer Full Flow/No By-Pass - This was our point of reference and was used to illustrate the need for by-pass filtration.

3. 40 Micrometer Full Flow/750 By-Pass - This was the level of performance we attempted to achieve with the SOBP filters.

4 & 5. 40 Micrometer Full Flow/Pleated Paper SOBP - Two tests were run with this particular filter combination to evaluate performance of the pleated paper SOBP.

6 & 7. 40 Micrometer Full Flow/Stacked Disc SOBP - Two tests were run with this particular filter combination to measure performance of the stacked disc SOBP. Oil capacity was also reduced in the second test to determine its effect on wear.

The three by-pass filters tested were a pleated paper spin-on filter, a stacked disc spin-on filter and a canister-type depth filter. The pleated paper SOBP was constructed from a special grade of fine pore filter paper whose absolute retention rating was 15 micrometers. The stacked disc SOBP was made from an extremely dense felt paper media with an absolute retention rating of 8 micrometers. Figure 5 shows a cutaway of the stacked disc SOBP filter.

The 750 by-pass filters used in these tests were depth-type filters whose media consisted of a blend of shreaded paper and graded hardwood chips. All were taken from the same production lot and sorted to insure consistency. Although the 750 is capable of removing particles as small as 3 micrometers, an absolute rating has no meaning because of the characteristics of a depth-type filter. All of the full flow filters used in these tests were spin-on's with an absolute retention rating of 40 micrometers. The grade and porosity of the filter paper were controlled as closely as possible to maintain a consistent level of filtration. Every pleated paper element, full flow or by-pass, was bubble tested to insure that there were no end seal leaks or paper ruptures.

OBSERVATIONS AND ASSUMPTIONS

The "full flow filter only" test was the test chosen as a common point of reference from which to measure the improvement in wear protection attributed to using a 750 by-pass, a stacked disc SOBP, and a pleated paper SOBP filter. This procedure was established in previous wear studies with similar results showing tremendous wear protection improvement when using by-pass filters(4).

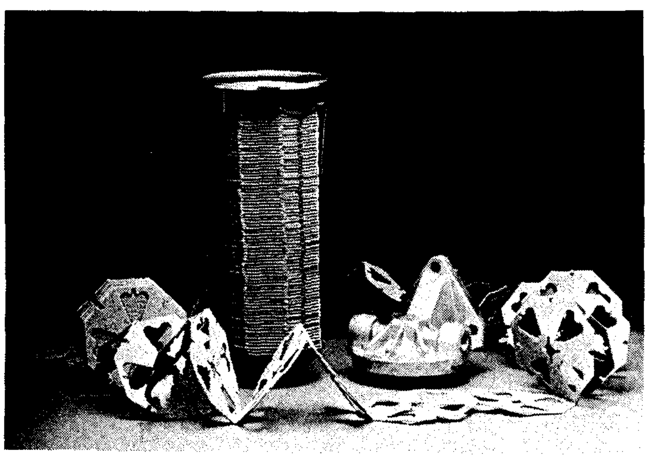

Fig. 5 - Cutaway view of stacked disc spin-on filter and media

The extraneous inputs introduced in dynamic tests of this kind are so numerous and complex that it would be impractical, if not impossible, to attempt to control them all. We minimzed those variables considered critical, realizing that a certain amount of repeatability error would be unavoidable. Although measurements were made and recorded for each individual bearing and piston ring, the results were presented as average values for the entire set of bearings and rings within each engine. The following observations were made with respect to individual component wear.

Main bearings wear at different rates depending upon their surface area. Reduction in wear surface area results in increased unit loading and a corresponding increase in wear. Since the NH engine has three different widths of main bearings, we would expect to see a corresponding variance in wear pattern. Also, the lower bearings wear at a faster rate than the upper bearings, due to downward loading of the crankshaft during combustion. Additional factors that affect main bearing wear are crankshaft straightness and deflection under load. The combined results of these factors make any direct comparison of individual component wear, without particular regard to the effect of these factors, invalid. Use of an average main bearing wear figure is strictly for convenience and not intended to imply any expectations by the authors for equivalent wear levels between parts.

Rod bearings and piston rings, unlike the main bearings, have no inherent design differences to cause large wear variances relative to location in the engine. Wear differences between upper and lower bearings are caused by increased bearing loads during combustion as the cylinder pressure forces the piston down in the bore and the top half of the rod bearing is loaded more heavily than the lower half.

There are four different rings on each piston (top compression, second compression, third compression, and oil control) which must be dealt with separately. In addition, liner etch quality is of extreme importance in determining ring wear rate. Since we cannot closely control or determine etch quality prior to testing, it is a randomly introduced variable affecting ring wear. Several key assumptions were made relative to our data analysis:

1. The wear characteristics of the three different engines used in this test did not differ significantly.

2. Rebuilding between tests introduced no significant wear variable.

3. Various test operations (weighing, assembly/disassembly, engine operation), were essentially identical for all tests.

4. A 150 hour test was suitable duration for testing of this kind.

5. A three engine test was definitive.

It should be noted that other conditions existed which could affect the degree of wear differential observed for the same filter combinations in field engines. For example, previous studies have shown that when adding large amounts of contaminants to the oil over a short period of time, the filtration system is limited in its ability to remove the dirt by the number of passes the oil makes through the filters. The result is a higher average oil contaminant level and corresponding wear rate. More dramatic than this was the method in which contaminants were added to the engines. In these tests, dirt was added every four hours in one lump sum rather than continuously as would be the case in normal operating conditions. Tests showed that the engine wear rate is much higher immediately after the contaminant is added than at the end of the four hour period(3, 4). Dirt settling also affects wear rate. Field engines are shutdown for extended periods of time allowing some dirt to settle out in the pan, which would also result in lower wear rates than observed in the test cell where the engine was run continuously. While the wear tests were run at full load and speed, we estimate that field engines normally operate at 50% to 75% of these values. Wear tests have shown that reduced load and speed result in lower wear rates(5).

The combined effects of these factors limit any direct comparison between expected field service life and laboratory engine test results. Field experience indicates that calculated wear life from laboratory engine tests are understated. However, if the calculated wear life with a combination full flow and by-pass filtration system is twice as long as a system without a by-pass filter, we would expect the field service life to be comparable(6).

LUBE SYSTEM CAPACITY

From previous studies of filter plugging, we know that oil degradation is related to a number of variables, one of which is the oil system capacity(7). The replacement of the 750 housing with a SOBP filter results in a net oil reduction of 7.57 liters (2 gallons) or approximately 20% for a 41.64 liter (11 gallon) system. Users extending oil drain intervals beyond 16,000 kilometer (10,000 miles) should be aware of the impact of reduced oil capacity. The service life of the oil is dependent upon the overall operating condition of the engine, its fuel and oil consumption, the total volume of oil available to disperse contaminants and combustion by-products, and the type and quality of the oil used. If a fleet is extending its oil drain intervals to the point where the oil is close to the end of its useful life, a reduction in oil capacity would necessitate a cutback in oil drain intervals. When the oil is extended beyond its limits, "dump out" and filter plugging ocurr. Since most full flow filter's dirt holding capacity is less than 454 grams (1 pound), plugging ocurrs very rapidly and can usually be detected by a drop in oil pressure(7). However, 4.8 million kilometers (3 million miles) field test accompanied by oil and filter analysis showed that a small sampling of trucks changing oil between 19,300 kilometers (12,000 miles), and 32,200 kilometers (20,000 miles) were within safe limits even after reducing their oil capacities by 7.57 liters (2 gallons). Exceptions were noted in cases where engines problems were diagnosed. A summary of the full flow filter restriction versus the change interval is shown in Figure 6. Filter plugging was not significant in those engines where oil capacity was reduced.

The user should be aware of limitations on oil drain intervals and those factors which affect it. Manufacturer's recommendations should be strictly adhered to and any deviation should be closely monitored with extreme caution. Although the 7.57 liter (2 gallons) oil reduction associated with the SOBP filter did not have any dramatic effects on engine wear, its impact on oil drain intervals must be determined on an individual basis. Since no two operations are alike, the maintenance intervals vary considerably utilizing engine oils to various degrees.

TEST RESULTS

All full flow filters in this test series were analyzed in the laboratory for presence of silica and wear metals. A 10.16 cm. by 10.16 cm. sample of paper was removed from each full flow filter then ashed and analyzed by an atomic absorbtion.

This 103.23 cm. sq. sample represented only 1% of the total paper area. It was assumed that the contaminant in each filter was uniformly distributed throughout the paper. In most cases, we saw increased amount of silicon and wear metals in the filter paper taken from those tests with higher wear rates. This corresponds to the fact that the by-pass filter lowers dirt content in the oil, leaving less contaminants to be removed by the full flow filter, resulting in less engine wear.

The oil samples were analyzed by the atomic absorption method. Samples were taken every 50 hours and analyzed for wear metals, silicon, sodium, and coagulated pentane insolubles. Uniform distribution of contaminants through the oil was assumed.

The oil analysis and filter analysis were reported as a percent reduction in dirt content and wear metal. This percentage was computed by comparing the results of each full flow and by-pass filter combination test to the full flow only filter test. Everything remaining constant this comparison showed a correlation to the amount of wear observed for each filter combination but not as good as was expected.

Our analysis of the data revealed that rod bearing wear was reduced 89% with the 750 by-pass, 87% with the stacked disc SOBP, and 64% with the pleated paper SOBP. Main bearing wear was reduced 93% with the 750 by-pass, 91% with the stacked disc SOBP, and 63% with the pleated paper SOBP. Ring wear was reduced 83% with the 750 by-pass, 73% with the stacked disc SOBP, and 59% with the pleated paper SOBP. One stacked disc SOBP test was run with the oil capacity reduced by two gallons and the rod bearing, main bearing, and piston ring wear was 5%, 4%, and 3% higher respectively as compared to a similar test with normal oil capacity. Figures 7 through 9 compare wear rate using average weight loss for each filter combination. Table 1 summarizes these data as percent wear reduction.

Laboratory filter analysis showed that dust trapped in the full flow filters was

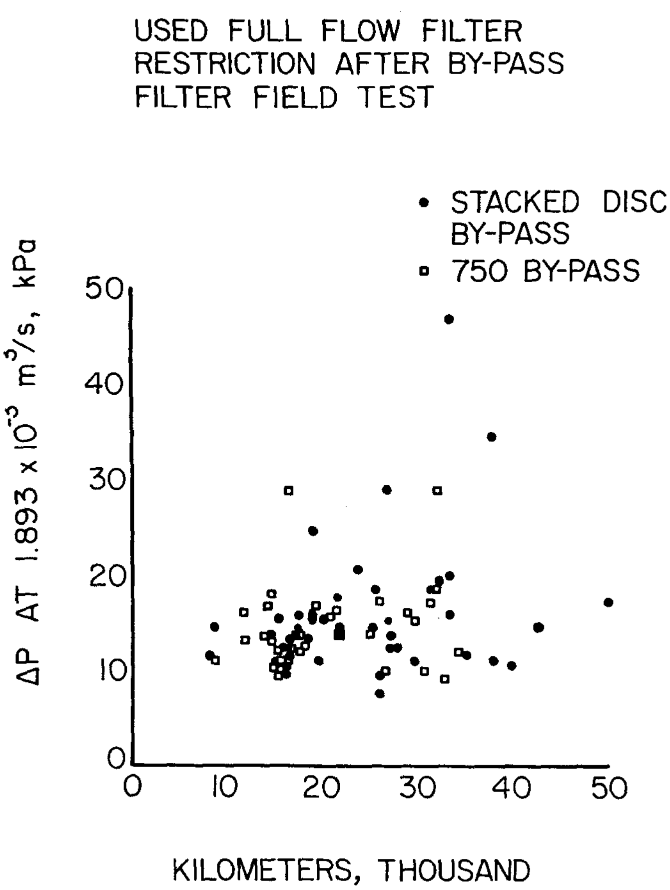

Fig. 6 - Full flow filter restriction from field test engines

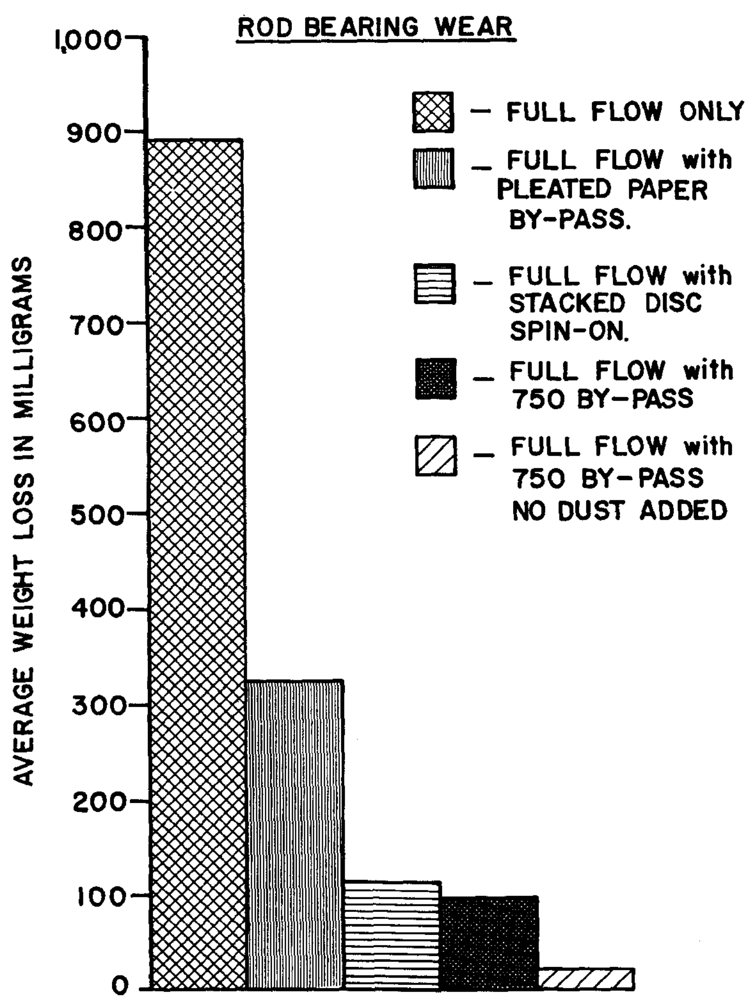

Fig. 7 - Comparative main bearing wear - 40 micrometer full flow filter base

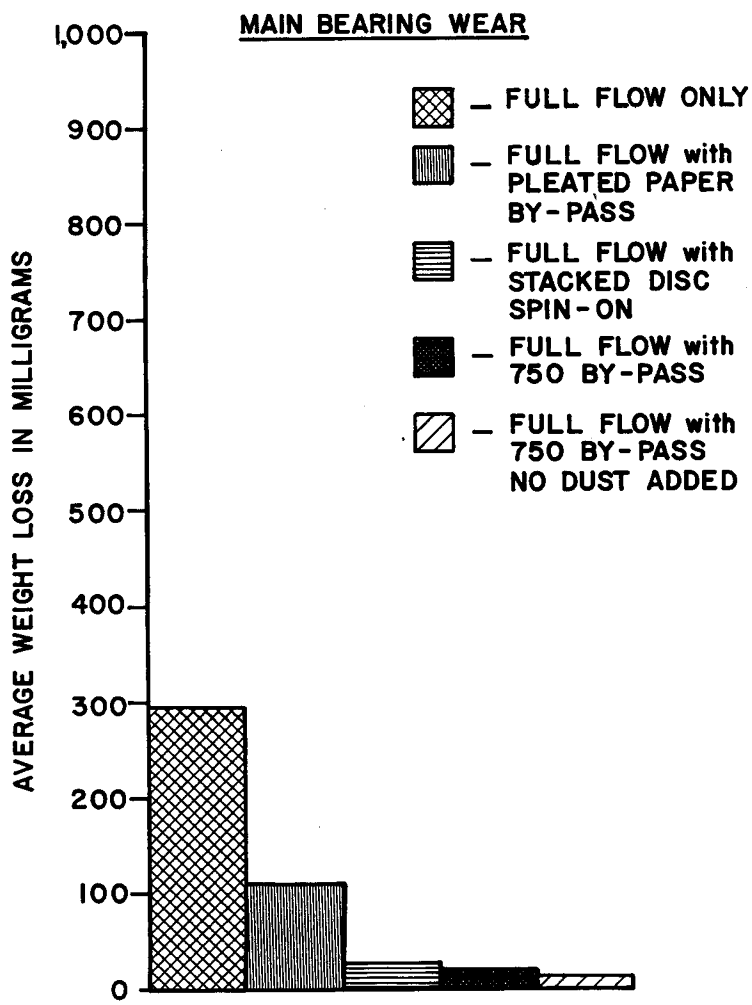

Fig. 8 - Comparative rod bearing wear - 40 micrometer full flow filter base

reduced 23% with the 750 by-pass and 22% with the stacked disc SOBP. No improvement was noted with the pleated paper SOBP. Wear metal content in the full flow filters was 89% lower with the 750 by-pass, 79% lower with the stacked disc, and 54% lower with the pleated paper SOBP. Photographs of bearings taken from test engines are shown in Figures 10 through 13. Table 2 shows dirt and metal content for the full flow filters used in each test.

Oil analysis revealed that a 98% reduction in silicon levels of samples taken from the 750 by-pass test, 87% reduction in the stacked disc SOBP test and 76% reduction in the pleated paper SOBP test. Similarly, the wear metal levels were 84% lower for the 750 by-pass test, 83% lower for the stacked disc SOBP test, and 70% lower for the pleated paper SOBP test.

Table 3 summarizes the oil analysis for each test.

In reviewing the inferior performance of the pleated paper SOBP filter combination, we concluded that this was the result of denser material used in the disc element, along with the combined effects of depth and surface filtration afforded by the disc design.

The data in this report does not lend itself readily to statistical analysis, because of the limited number of data points observed. Our conclusions were based on results of wear levels as it related to oil contamination and filtration. This was verified in our oil and filter analyses from past engine tests and with the tremendous amount of backup bench test data which preceded this wear test study.

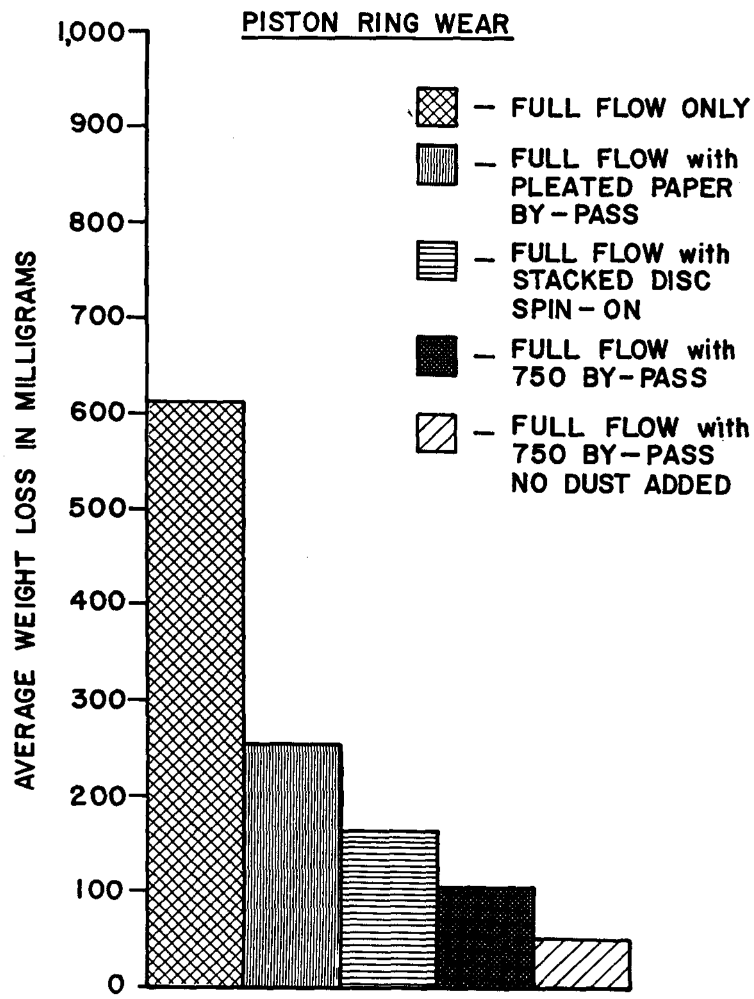

Fig. 9 - Comparative piston ring wear - 40 micrometer full flow filter base

Table 1

Engine Wear Test

Percent Wear Reduction
Using By-pass Lube Filters

By-pass Filter Description	Rod Bearings	Main Bearings	Piston Rings	Average
750 By-pass	89%	93%	83%	88%
Stacked Disc.	87%	91%	73%	83%
Pleated Paper*	64%	63%	59%	62%
750 By-pass - No Dust	98%	96%	92%	95%
Stacked Disc with 2 Gallons Less Oil	82%	87%	70%	80%

*Average of Two Tests

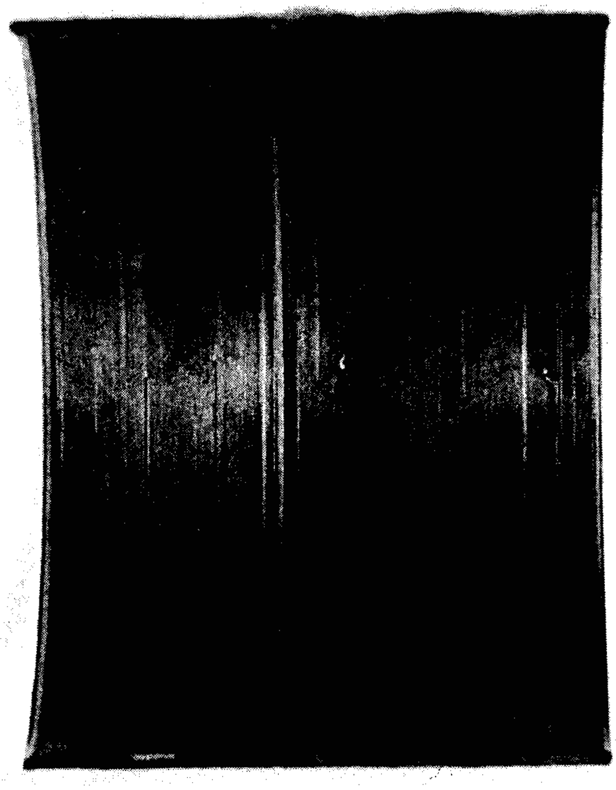

Fig. 10 - Lower main bearings from test without by-pass filter

Fig. 12 - Upper rod bearings from test without by-pass filter

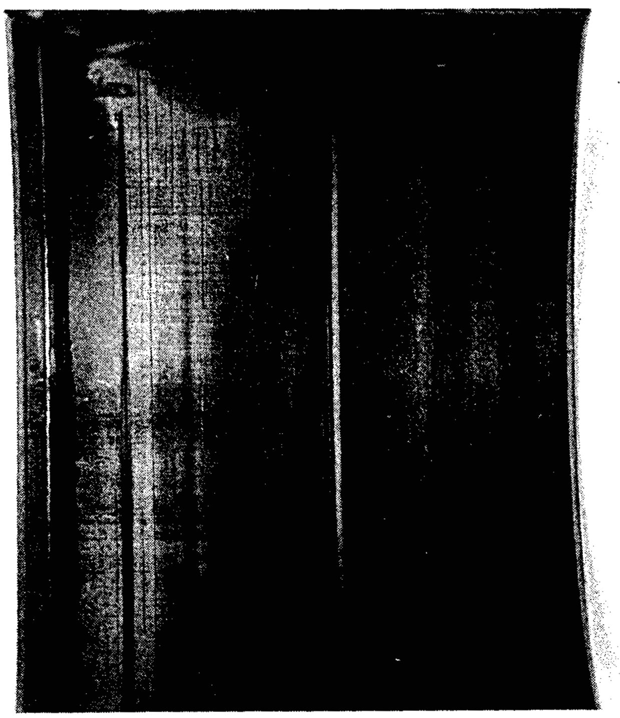

Fig. 11 - Lower main bearings from test with by-pass filter

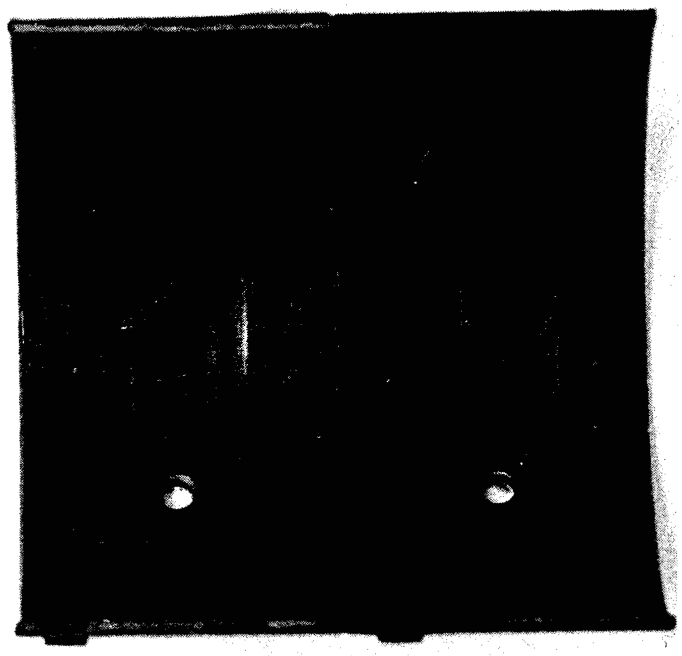

Fig. 13 - Upper rod bearings from test with by-pass filter

Table 2

Engine Wear Test

Estimated Weight in Grams
of Contaminants Trapped by
The Full Flow Filters

	Si	Fe	Cu	Pb	Sn
40 Micrometer Full Flow - No By-pass (base)	128.8	32.6	1.5	.8	1.6
40 Micrometer Full Flow - 750 By-pass	98.56	2.8	.2	.15	.84
40 Micrometer Full Flow - Pleated Paper SOBP	140.4	10.1	.6	.4	.94
40 Micrometer Full Flow - Pleated Paper SOBP	118.5	12.3	.3	.15	1.2
40 Micrometer Full Flow - Stacked Disc SOBP	108.4	6.7	.2	.2	.7
40 Micrometer Full Flow - Stacked Disc SOBP with 2 Gallons less oil	96.6	5.6	.2	.1	.2

:OST ANALYSIS

All comparative wear data in this and ›revious test studies show that the use of ؛n effective by-pass filter in combination ‹ith a good full flow filter would greatly ·xtend the life of critical engine parts. se of the by-pass filter requires dditional expense including initial cost, eplacement elements, additional oil, and abor to service. Maintenance costs for ngine service and filter changes vary onsiderably between types of engine perations. However, costs on a per mile r per hour basis for scheduled maintenance ntervals are extremely sensitive to verhaul periods. For a small ex- ention in engine life, a by-pass filter ın more than pay for itseıı. Spin-on by- ıss filters can offer an even lower cost ıan the conventional 750 from labor and ؛l savings, even though the spin-on re- acement elements are more expensive. :her benefits such as foolproof service ·e not quantifiable. Cost factors and as- ımptions considered in this study include

ı Labor costs for filter changes; 2) Oil ›st and savings; 3) Initial by-pass filter ›using cost; 4) Standard maintenance ıterval cycles, and; 5) By-pass filter re- acement cost. Appendix A and B gives a ·eakdown of these analyses.

Table 3

Engine Wear Test

Oil Analysis Summary

Reported in PPM
150 Hour Sample

	Si	Fe	Cr	Sn	Pb	Cu	Al	Na	Percent Coagulated Pentane Insolubles
40 Micrometer Full Flow - No By-pass (base)	185	158	18	35	200	168	59	24	1.28
40 Micrometer Full Flow - 750 By-pass (no dust added)	4	22	3	2	8	46	11	5	1.77
40 Micrometer Full Flow - 750 By-pass	4	7	1	4	11	72	7	2	.53
40 Micrometer Full Flow - Pleated Paper SOBP	44	28	2	2	53	67	10	11	.96
40 Micrometer Full Flow - Pleated Paper SOBP	47	40	5	5	74	90	16	12	1.06
40 Micrometer Full Flow - Stacked Disc SOBP	24	28	2	2	18	50	9	7	.91
40 Micrometer Full Flow - Stacked Disc SOBP with 2 Gallons less oil	40	36	5	6	35	67	13	10	.15

The results of this study indicate that the cost of using by-pass filters can be offset through extended engine life resulting from reduced wear.

SUMMARY AND CONCLUSIONS

From the results of these tests, we conclude that:

1. After comprehensive tests of over two hundred different types of filter media, the stacked disc spin-on by-pass filter and the conventional 750 depth-type filter were the only filters to effectively reduce engine wear by controlling the small abrasive particles in the oil. The stacked disc spin-on by-pass filters reduced engine wear as effectively as the 750. The pleated paper spin-on by-pass filter was found to pass bench test requirements, but was proven to be ineffective in actual engine wear tests.

2. A reduction in engine oil capacity of 7.57 liters (2 gallons) did not substantially affect the engine wear. However, reduced oil capacity may affect maintenance intervals. Engine manufacturers recommendations in establishing change intervals should be followed.

3. Engine wear was directly related to the degree of filtration of the by-pass and full flow filters and the levels of abrasives left in the oil.

4. The use of the combination full flow and by-pass filter system can reduce the wear rate to less than 1/2 that resulting from use of a full flow only filter system.

5. Due to extended engine life with the use of an effective by-pass filter, the extra cost of installing and maintaining the by-pass filter is recovered many times over, providing the lowest total cost for the engine user.

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Appendix A

Cost Analysis for By-pass Filters

Cost Assumptions (1)	System With No By-pass	750 By-pass	SOBP
Full Flow Filter (spin-on type)	$8.00	$8.00	$8.00
Labor to Change Full Flow Filter Element & Oil at $20.00 per hour	8.60	8.60	8.60
Oil at $1.25 per Gallon	10.12 (8.1 gal.) 30.7 liters	13.75 (11 gal.) 41.7 liters	11.25 (9 gal.) 34.1 liters
By-pass Filter	-	3.25	8.00
Labor to Change By-pass Element at $20.00 per hour	-	8.40 (25 min.)	3.34 (10 min.)
Total Cost for Lube Oil and Filter Change	$26.72	$42.00	$39.19
Service Interval (2)	14,000 miles (22,526 km)	18,000 miles (28,962 km)	16,000 miles (25,744 km)

1. These costs are based on averages and may vary in different areas.
2. Change intervals recommended in Cummins Service Parts/Topic No. 77T7-9, based on oil consumption of 600 miles per quart or 1,020 kilometers per liter and fuel consumption of 5 miles per gallon or 2.1 kilometers per liter.

Appendix B

Oil System Operational Cost Per Mile

	200,000 Mile Overhaul 321,800 Kilometers			300,000 Mile Overhaul 482,700 Kilometers			400,000 Mile Overhaul 643,600 Kilometers		
	No By-pass	750	SOBP	No By-pass	750	SOBP	No By-pass	750	SOBP
Overhaul Period	200,000 mi. 321,800 km.	205,479 mi. 330,615 km.	207,603 mi. 334,033 km	300,000 mi. 482,700 km.	313,589 mi. 504,565 km.	317,439 mi. 510,759 km.	400,000 mi. 643,600 km.	424,528 mi. 683,066 km.	431,616 mi. 694,470 km.
Number of changes between overhauls (x cost of:)	14.3	11.4	13.0	21.4	17.4	19.8	28.6	23.6	26.98
Full Flow Filters	$114.40	$91.20	$104.00	$171.12	$139.20	$158.40	$228.80	$188.80	$215.84
Labor to change full flow filters	122.98	98.04	111.80	184.04	149.64	170.28	245.96	202.96	232.03
Oil	144.72	156.75	146.25	216.57	239.25	222.75	28[illegible].43	324.50	303.53
By-pass Element	-	37.05	104.00	-	56.55	158.40	-	76.70	215.84
Labor to change by-pass filter	-	95.76	43.42	-	146.16	66.13	-	198.24	90.11
In-frame Overhaul	3,000.00	3,000.00	3,000.00	3,000.00	3,000.00	3,000.00	3,000.00	3,000.00	3,000.00
TOTAL COST OF OPERATION BETWEEN OVERHAULS	$3,382.10	$3,478.80	$3,509.47	$3,571.23	$3,730.80	$3,776.00	$3,7[illegible].19	$3,991.20	$4,058.13
COST PER MILE/KM OF OPERATION (mils)	.0169 mi. / .0105 km.	.0169 mi. / .0105 km.	.0169 mi. / .0105 km.	.0119 mi. / .0073 km.	.0119 mi. / .0073 km.	.0119 mi. / .0073 km.	.0094 mi. / .0058 km.	.0094 mi. / .0058 km.	.0094 mi. / .0058 km.
CONCLUSIONS:	Extending a normal 200,000 mile overhaul interval by 3% or 4% (5,479 or 7,603 mi.) pays for the use of a by-pass filter.			Extending a normal 300,000 mile overhaul interval by 5% or 6% (13,589 or 17,439 mi.) pays for the use of a by-pass filter.			Extending a normal 400,000 mile over haul interval by 6% or 8% (24,528 or 31,616 mi.) pays for the use of a by-pass filter.		

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