Advanced Technology

Conference

DRIVES AND CONTROLS

Magnetic Filtration

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Session 3 Paper 3

Introduction

The working fluid systems of engines, gearboxes and hydraulic machinery are all prone to contamination generated internally, as well as contaminant ingested from external sources. The minute metal particle, considered the most harmful in such systems, is responsible for at least 60% of engine wear and an even larger percentage of hydraulic failure.

The filter, in the conventional sense of the term, is essentially a selectively porous barrier fitted to a system to protect it - its function, to separate contaminant from the circulating fluid. However, because there are inherent physical limitations to the use of a barrier, such filters are sometimes unable to remove the tiniest particles most harmful to the system. In addition, any barrier used for such a purpose will inevitably become less and less porous to the filtrate as it fills with solid contaminant.

1. Contamination and System Cleanliness

The cleanliness level required for efficient system operation is largely determined by the 'clearances' between adjacent working surfaces.

'Clearance size' particles range from 0 to 25 microns in size and are capable of causing degradation of internal surfaces. Larger particles, 'chips', are capable of more immediate catastrophic failure. Typical clearances in a hydraulic system are shown in Table 1

Component	Item	Typical Clearance µm
Gear Pumps	Gear tip to case	0.5 - 5
	Fixed side clearance	25 - 50
Vane pumps	Vane tip to case	0.5 - 1
	Vane side to case	5 - 13
Piston pumps	Piston to bore	5 - 40
	Valve plate to cylinder	0.5 - 5
Control valves	Spool	5 - 13
	Disc	0.5 - 1
	Poppet	13 - 40
Servo valves	Spool	1 - 4
	Flapper	18 - 63
Cylinders	Piston to bore	50 - 250
	Rod bearings	1.5 - 10
Actuator bearings	Plain/Sliding/Rolling	1.5 - 10

1.1 Sources of contamination

Brand new machines often emerge heavily laden with contamination, namely metal 'swarf', from the machining/ manufacturing process. Purging systems are therefore employed to 'wash out' most of the 'swarf' inherent to manufacture and assembly.

Systems are also prone to contamination from the fluid used to lubricate it. If the fluid is stored in metal containers, erosion of the internal container walls can result in the introduction of small metal particles into suspension in the new fluid. For systems that are not completely sealed from their environment, external material can also be ingested during operation.

2. The Damage

'Clearance size' particles, too fine to be halted at the filter, progress through the system to initiate component wear (fig.1). This wear, in turn, results in ever-increasing amounts of particulate matter in suspension. Larger particles, left in circulation through by-pass operation or otherwise, can cause mechanical interference between adjacent working surfaces. High-pressure systems impart high velocities to any contaminant particles, with additional surface wear being the consequence.

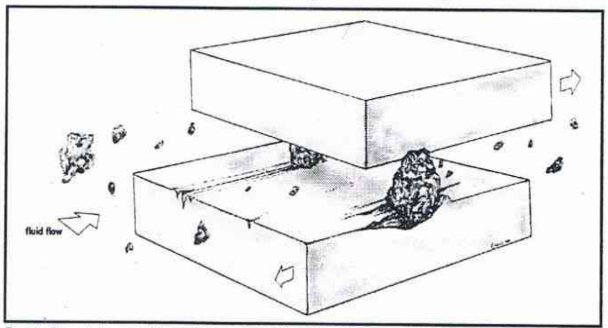

Fig. 1 Breakdown of bearing surfaced by clearance size particles (cause of boundary layer rupture)

Particles are generated internally during operation through the following types of wear:

i. *Abrasive Wear* Hard particles spanning the 'clearance' between two moving surfaces can scrape one or both surfaces

ii. *Cavitation Wear*	If the inlet flow to the pump is restricted, resultant imploding fluid voids could cause shocks that break away surface material.
iii. *Erosive Wear*	Fine particles borne by fluid at high velocity can erode away a metering edge or critical surface.
iv. *Adhesive Wear*	Lubricant starvation at certain points will allow metal-to-metal contact between adjacent moving surfaces.

Table 2 shows typical size ranges of particles generated by different types of wear.

Type of Wear	Typical size of particle
Abrasive Wear	5 - 250 µm
Contamination & Erosion	40 - 250 µm
Surface fatigue	5 - 50 µm

Table 2

3. The Conventional Filter

The porosity of a given filter determines the mean size of particle that can be retained at the barrier. The clearance sizes in the component pumps, vanes, valves, etc. determine the filter rating required. Machine and hydraulic component manufacturers specify ISO cleanliness levels to ensure that machine and component performance is optimal. (Table 3)

System	**Recommended Filter Rating**
Low pressure systems with generous clearances	25 - 40 µm
Low pressure heavy duty systems	15 - 25 µm
Typical medium pressure industrial systems	12 - 15 µm
Mobile hydraulic systems	12 - 15 µm
General Machine tool & other high quality systems	12 - 15 µm
High performance machine tool & other high pressure systems where reliability is critical	3 - 5 µm
Critical high pressure systems & controls using miniature components	1 - 2 µm

Table 3

3.1 The Limitations to Barrier Filtration

Filters employing a barrier have two principal limitations:

A contaminant particle will only be retained at a partially porous barrier if it chances across a pore opening smaller in size than its own dimensions. Hard particles smaller than this critical mean pore dimension will remain in suspension and accelerate internal wear (fig. 2). However, because the pores have to be large enough to let the lubricant through, there is a limit to which matrix porosity can be reduced.

Particles trapped at the barrier present an ever-decreasing amount of surface area available to those particles still in suspension. As the filter medium self-obstructs with more and more contaminant, fluid flow is increasingly impeded until, with the filter medium virtually saturated, fluid flow rate is impracticably reduced for efficient lubricant function (fig. 3).

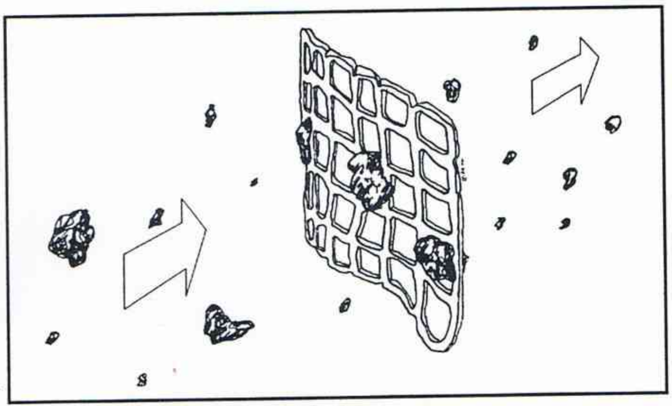

Fig. 2 Smaller particles unfiltered at barrier

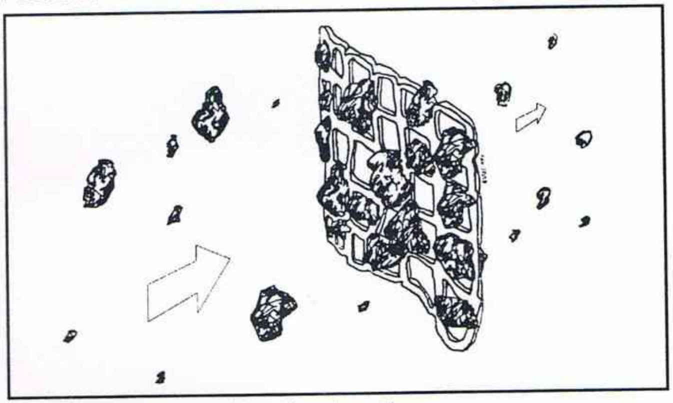

Fig. 3 Fluid flow obstructed by collected particles

It is essential that the filter fitted keeps the working clearances in the system free of abrasive contaminant.

Fibreglass filter matrices generally tend to have smaller pore sizes (10 - 25 microns) than cellulose (paper) elements (25 - 40 microns) and are thus able to retain smaller sized particles. However, two significant negative consequences result from 'finer' filtration -

- ➢ the filter matrix will block up quicker, and
- ➢ the additives in the oil are also likely to be degraded, thereby negating any intended benefit by their presence.

A cellulose filter element is capable of holding only a few grams of contaminant even with 'coarse' filtration. Fibreglass filters generally have finer filtration capability and are usually more costly. Unfortunately, however, they need more frequent replacement (unless a much larger size filter is used). The barrier area, although more efficient than a 'coarser' element is nonetheless finite and obstructs much more quickly. Systems are fitted with filter by-pass facility to ensure that the system continues to circulate lubricant even when the filter is blocked. Because finer filters need more expensive and frequent replacement, financial constraints to system maintenance limit the required frequency of filter replacement. Systems with blocked filters are then dangerously left operating in 'by-pass' mode. In such instances, the benefits of fitment are lost - with all contaminant over and above the capacity of the matrix, left in circulation until the filter is eventually renewed. In the meantime, clearance size particles have the opportunity of generating more super hard material through self-disintegration and surface erosion of internal surfaces, often with catastrophic consequences.

Replacing the fluid (cutting, hydraulic, lubricant) removes some of the contaminant, but when fluid is drained from the system, particles tend to both adhere to the internal surfaces and settle on the internal horizontal faces. Heavier material settling under gravity at the bottom of the sump or reservoir remains there, if not agitated in the draining process. The particles remaining are put back into suspension when new fluid is introduced into the system.

If the majority of hard metal contaminant could be removed consistently, not only would the lubricant be cleaner, but also the system would suffer from significantly less mechanical wear.

4. Magnetic Filtration

4.1 Previous attempts at Magnetic Filtration

As the majority of hard metal particles are ferrous (iron), the idea of using a magnet to draw metal from fluid is not in fact new.

The 'magnetic sump plug' was introduced in the 1960's in the 'Mini' car. Its common engine and gearbox lubrication resulted in its notorious generation of copious amounts of 'swarf'. However, the 'plug' only tends to attract metal particles that happen to circulate past the relatively small magnetic field around it, at the bottom of the sump. Worse still, there is always the risk that mechanical vibration and fluid turbulence could wash the particles off. Because particles attached would gain magnetisation through contact with the magnet, they would aggregate in clumps. If such a clump were then to wash off, it would pose even more of an immediate threat of mechanical interference and failure than the particles did as individual shards. Magnetised particles of clearance size would also be in danger of magnetic attachment to bearing surfaces.

Magnets placed at the bottom of a filter canister and magnets strapped to, or coiled around the outside of a standard filter housing are similarly random in their treatment of the total throughput of metal contaminant. Such devices are thus are incapable of removing all of the ferrous contaminant from the circulation.

Barriers that are magnetised (to increase collection area) suffer the same drawbacks as conventional barrier filtration - that of gradual blockage with contaminant collection. In addition, particles at such barriers can be difficult to clean off and re-use.

Most magnetic devices suffer from their inability to retain particles once attracted to the magnet. This handicap thus prevents their efficient function in situations where vibration is heavy, and where fluid flow and pressure are high.

5. MAGNOM™ Magnetic Filtration

5.1 Overview of the benefits of MAGNOM filtration

MAGNOM technology employs barrier-free filtration. It can remove 100% of all magnetisable metal particles in fluid circulation and is completely re-usable.

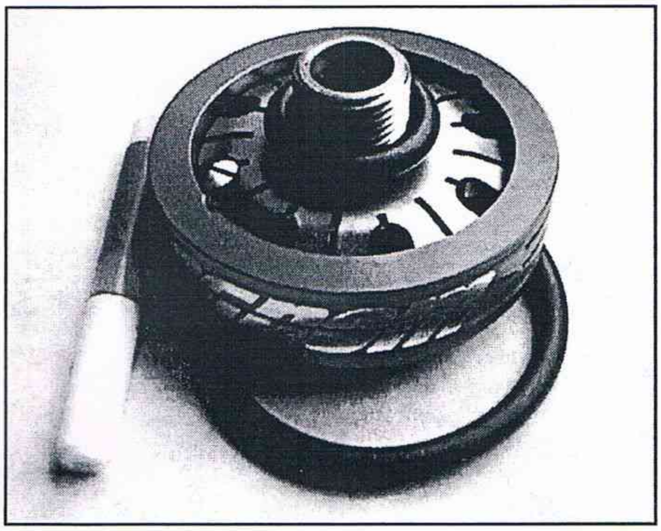

Fig. 4 MAGNOM spin-on Filter Module

It locates either:

1) in-line with a conventional filter, (between the filter head and conventional filter) (fig. 4) or
2) directly into a fluid line (figs. 5a & 5b) (a purging system, hydraulic line, fuel line).

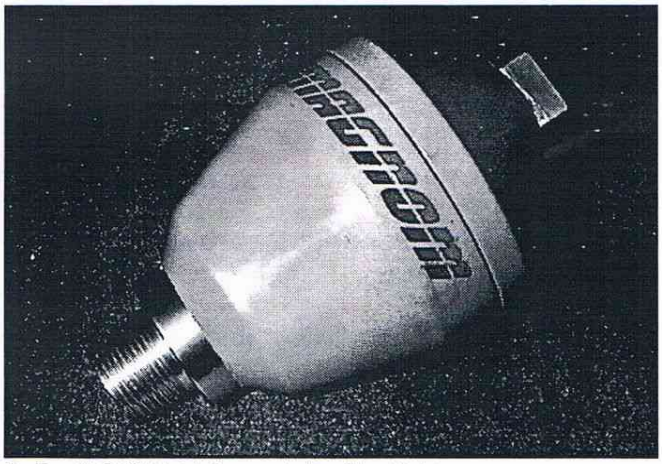

Fig. 5a MAGNOM High Pressure In-Line Filter Module

Because of its location, filtration is 'systematic' as opposed to 'random' in function. A unique orientation of magnetic fields in the device enables metal particles to be drawn from fluid flow and retained in parts of the module, which are out of fluid flow.

The modules are re-usable in their entirety. When serviced, metal debris can be viewed (on the core unit) in its trapped state (fig. 6) - thereby giving visible and early indication of any mechanical wear. MAGNOM can be fitted to any fluid system prone to ferrous particle contamination.

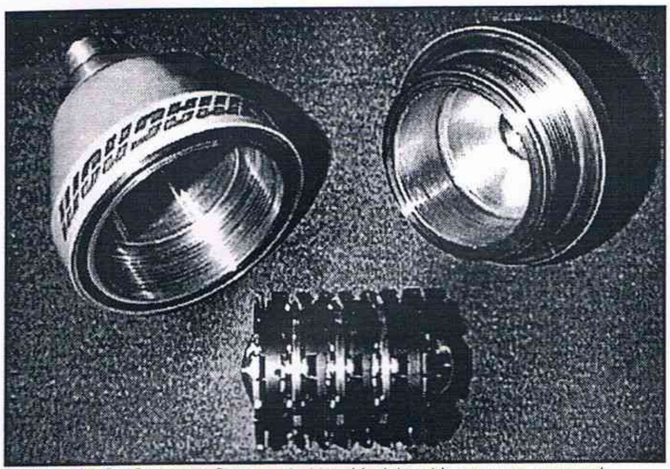

Fig. 5b MAGNOM High Pressure In-Line Module with core unit exposed

5.2 How MAGNOM™ technology works

Each magnetic module (figs. 4 & 5) consists of a housing and at least one core unit (fig. 7), of a magnet sandwiched between two metal plates. One plate gains magnetic North polarity, the other, South. Each plate has a radial distribution of 'fingers' and slots. The 'fingers' of facing plates are aligned with one another so that each pair 'sandwiches' a zone of magnetic attraction. The slots, in turn, become regions of magnetic repulsion, because the like poles of neighbouring fingers border either side of each slot. Because of the symmetric arrangement of fingers and slots, the slots of facing plates also line up in pairs. An aligned slot pair thus forms a channel of magnetic repulsion.

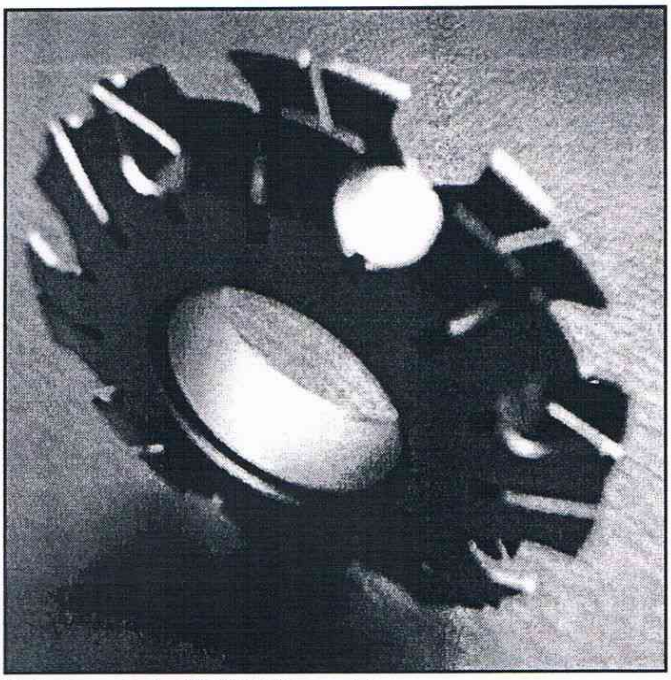

Fig. 7 Core unit of a MAGNOM filter module

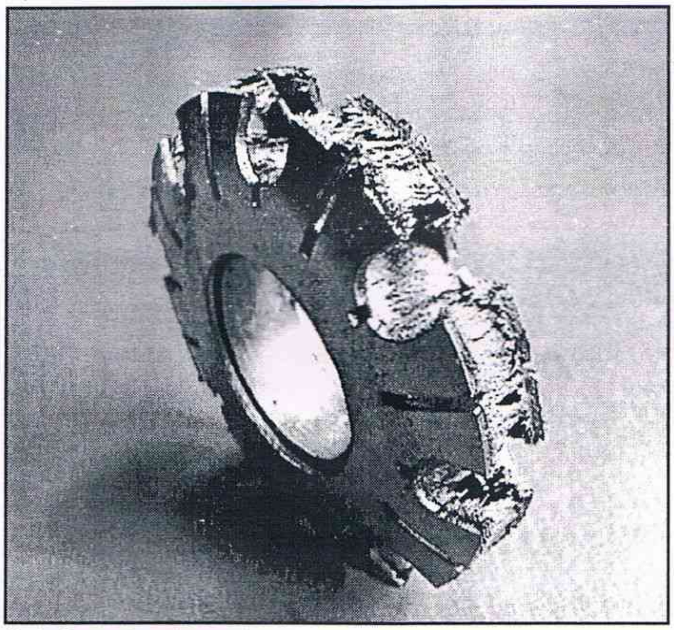

Fig. 6 Contaminated core unit

The resultant arrangement has particle collection zones (attraction zones between finger pairs) and repulsion zones (channels between slot pairs).

When apertures in the housing are aligned with the channels in the core unit, all fluid flow through the module is then only by means of these radially arranged channels. Fluid, and thereby the particles held there in suspension, are able to enter the module only via these channels. Whilst in the channel, any magnetisable particle is subject to two sets of magnetic fields:

Attraction of the particle towards the nearer of the two collection zones bounding the channel,

Repulsion of the particle away from the channel, but towards the 'more attractive' collection zone.

It is the orientation of these two co-operating magnetic fields that enables particles to be retained in the module (fig. 6) without danger of wash-off back into the downstream flow despite high fluid flow and pressure.

Sample Number	Test Time (minutes)	Mass of Iron powder added per time increment (g)	Culumative Mass of Iron Powder Added (g)	Corrected Mass of Iron Powder in Oil Sample (g)	Mass of Iron Powder remaining in Oil Sump (g)	Filtration Efficiency (%)
T2/1	10	6.3310	6.3110	0.1080	2.1600	65.78
T2/2	20	6.3102	12.6212	0.1389	2.7789	77.89
T2/3	30	6.3109	18.9321	0.1842	3.6840	80.54
T2/4	40	6.3104	25.2425	0.1731	3.4620	86.29
T2/5	50	6.3105	31.5530	0.1775	3.5500	88.75
T2/6	60	6.3108	37.8638	0.2118	4.2360	88.81

Table 4

6. Tests

6.11 MIRA (The Motor Industry Research Association) has tested the single core module.

In this test, 6 grams of fine iron powder were added at 10-minute intervals over an hour-long period. The module (approx. 75mm diameter, 20mm depth) collected (in a single pass) nearly 90% of the debris added. The module would have collected 100% of the iron powder, had the test period been longer. The results are represented in Table 4 graphically in fig. 8.

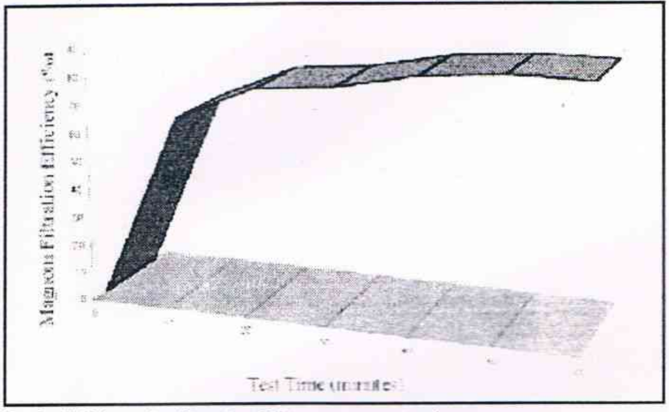

Fig. 8 MIRA results (Filtration Efficiency vs. test time)

6.12 TÜV The module has German TUV Certification: NR9710 9294 001

6.13 Flow & Pressure Tests

In further independent tests, the unit shown in fig. 5 can accommodate flow rates of 430 litres per minute and pressures in excess of 5000psi.

This particular module will hold over 200 grams (7.5 oz) of contaminant.

A comparably sized conventional filter will hold only 15 grams of contaminant before it is filled to capacity and working on by-pass.

Units larger than this standard unit will accommodate higher flow rates and higher contaminant capacities.

6.2 Live Tests

6.21 Ford Motor Company

Gear manufacturers, CNC/ Production machine tool operators experience the common problem of metal contamination from the manufacturing process. For a metal expansion coefficient of 50:1, a given volume of metal removed could generate 50 times its volume in steel chippings, presenting a larger contaminant surface area to the filter than the 'parent' block. In a conventional filtration arrangement, larger shards can be removed by conveyor or drum filtration. In most applications, however, the smaller clearance size particles have proved to be the ones most difficult to remove cost effectively.

The FORD MOTOR COMPANY Transmission Plant in Halewood, Merseyside has successfully tested an in-line module (HP-IL Series) on one of its gear cutting machines (fig. 9). The image of the contaminated four-core module (fig. 10) demonstrates not only the greater efficiency of metal particle collection, but also the vastly increased contaminant capacity attainable with this technology.

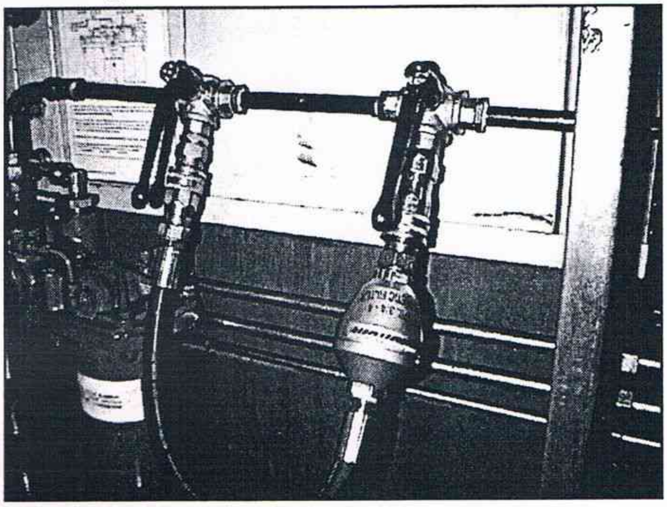

Fig. 9 MAGNOM Fitment at Ford Motor Co.

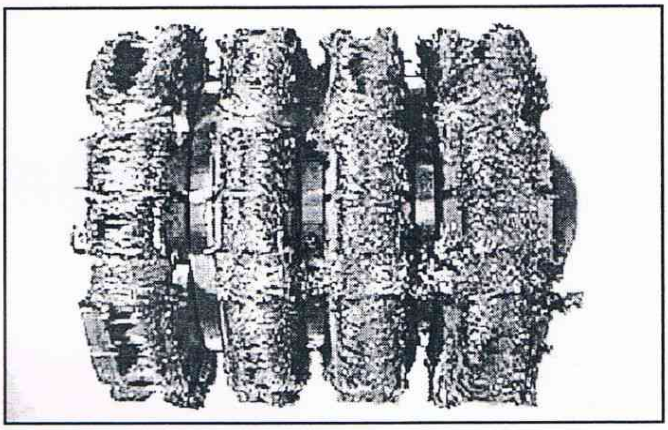

Fig. 10 Contaminated core from live test at Fords

6.22 Gearbox Manufacturer's results

The gearbox purging system of another leading manufacturer of earth moving equipment uses banks of filters in packs of four to purge newly manufactured gearboxes and systems. Previously, they were able to purge a maximum of 40 complete units per bank of four filters. However, with the inclusion of the HP-IL Series fitted in-line prior to the filter banks, the number of units purged was extended to a minimum of 57! The fitment of the MAGNOM HP-IL Series therefore extends conventional filter life by at least 40%. MAGNOM has not only produced significant financial benefits, but also offers finer ferrous particle extraction and consequently system protection than this company's conventional filtration. Put into economic terms, MAGNOM technology in this application saves this company 40% of an annual filter cost of £120,000 amounting to £48,000 saving per annum. This is an on-going saving for a once only installation and investment.

The same company performed live tests with the MAGNOM PFU (Pre-filter unit) Series fitted to their latest model transmission.

Laboratory analysis reflected the same findings as those of their production technicians - in that the Unit was removing particulate matter ranging from less than a micron to millimetres in size, prior to entering their conventional filtration. The significant protection offered by MAGNOM was found to prolong not just filter life, but lubricant life and transmission life as well!

Greater contaminant capacity

A MAGNOM magnetic module one quarter the size of a comparable conventional filter will hold ten times the amount of contaminant. (i.e. A MAGNOM module will hold 40 times more contaminant than a conventional filter of comparable size)

At capacity, the conventional filter is blocked (and being by-passed), but MAGNOM will still allow fluid to flow. Even more importantly, it will remove the damaging clearance size particles left in circulation by conventional filters. Such technology is invaluable to a system even if it were to be discarded after use - but its re-usability offers on-going saving and protection!

Any debris collected is easily cleaned off (with an air line for example) when the module is serviced. As the MAGNOM's capacity is larger than that of a standard filter, in certain applications, the service intervals can in fact be extended - thereby saving on costs and loss of production incurred in 'down-time'. The absence of any moving parts in this technology means that the modules do not wear - and should last indefinitely!

The technology is simple and yet obvious in hindsight.

7. Conventional Methods of Detecting Component Wear

7.1 Analysis of Filter Matrix

Filter matrix analysis (by magnifying glass or spectrographic analysis) is essential in the aircraft industry as the detection of fine particulate material from component wear will give important prior warning of imminent component failure.

7.2 Analysis of Lubricant

The detection of an increase in ferrous content (through particle count) in an oil sample often precedes critical level system failure by only a matter of hours.

7.3 Consequences of Failure to Detect System Wear

The debris generated from the wear of a single component is circulated around the system by the same lubricant designed to protect it. In doing so, it is thus able to cause wear in previously undamaged working surfaces. This secondary wear then generates its own source of particulate matter, the dispersal of which, in turn generates yet more contaminant. The overall wear rate of the system through erosion and corruption of boundary layer lubrication then accelerates with each 'pass' of fluid. This viral-like increase in particle number means that complete system failure is not a question of whether or not it will happen, but 'when'.

The job of the filter cannot be underrated.

Even the finest barrier filter will not remove the smallest metallic particles - the barrier after all, has to be porous enough to allow the lubricant through. Because MAGNOM filtration does not employ a barrier, there is no limit to the size of particle that can be filtered. It also evident that its capacity for contaminant far exceeds that of a comparably sized conventional filter.

The Electron Micrograph (fig. 11) of a sample collected in a core unit shows that not only ferrous particles are attracted to the module, but also non-ferrous matter such as aluminium and bronze.

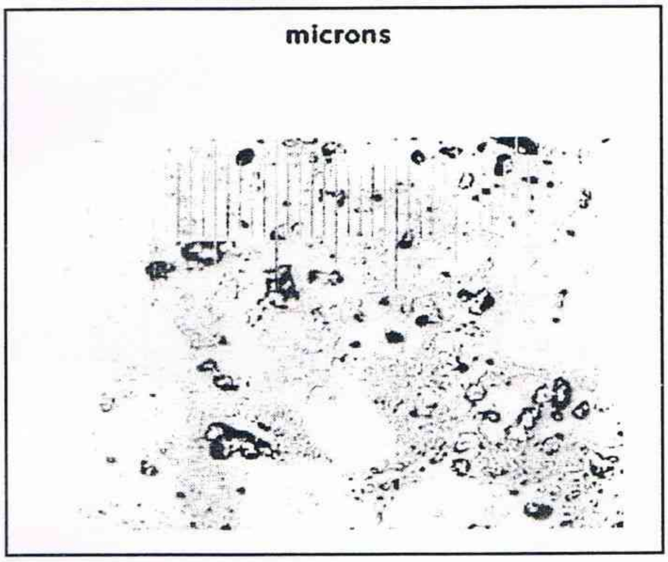

Fig. 11

8. The FINANCIAL benefits of MAGNOM Filtration

- Reduced likelihood of component/ system replacement & downtime from system failure
- Reduced system wear (through reduction of usual metal degradation)
- Accuracy of machine tool function maintained & tool life increased
- Prolonged fluid/ lubricant life & saving in disposal costs
- Prolonged conventional filter life & saving in disposal costs
- Increased service intervals & saving on 'down-time' expenditure & production loss
- Machine reliability improved
- Indicator of premature mechanical wear/ failure

The ECOLOGICAL Benefits of fitting MAGNOM technology

- Less scrap machinery (from failure to detect component wear at an early stage)
- Less conventional filters disposed of

- Less lubricant, cutting fluid, etc disposed
- Less pollution with more efficient mechanical function.

MAGNOM technology offers finer metal filtration than that offered by conventional elements. It is easy to fit and is easy to clean ready for re-use time and time again.

In short, MAGNOM technology has proved to be and will continue to be the best value component that can be fitted to any system prone to ferrous debris contamination.