Size is not important … Threat is!
Improving Fluid Power System Reliability

Jobey Marlowe
Vice President of Technology
Magnom Corporation

ABSTRACT

The paper identifies a historical misinterpretation in measuring hydraulic system condition and reliability, namely that fluid cleanliness is judged by measuring the size of the particulate contaminant removed from the system rather than by the ultimate threat posed by the contaminants material composition.

It will outline the historic approach to contaminants prevalent throughout fluid power equipment and the industry and introduce an important potential for improvement that has, up to now, been underappreciated. It will then explain how filtration technologies have inherent limitations that force compromises in the design, manufacture and use in fluid power systems. Over time these limitations have driven industry practice and thinking and possibly contributed to a limited view of the problem itself and the potential solutions available.

The paper will then explore an innovative approach that provides a very simple alternative technology proposition that will deliver improvements in efficiency and performance for new & existing fluid power, lubrication systems (and indeed water and gas systems).

TABLE OF CONTENTS

INTRODUCTION

This paper explains how the strategic deployment of a simple technology within critical fluid power systems, brings about very specific benefits that have previously not been possible.

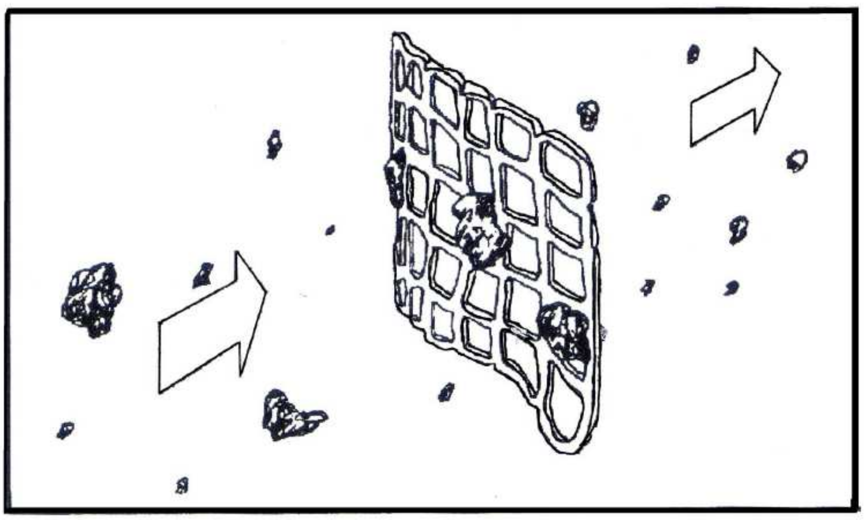
Using detailed and documented evidence from independent sources as well as end user real life system experiences, the paper will validate the proposition and the technology.

HISTORICAL PROBLEMS IN FLUID SYSTEMS

CONVENTIONAL FILTRATION…A HISTORICAL LEGACY

Sieve/barrier or interception type of filtration, whether it is 5 micron absolute filter or a 200 mesh screen, all work primarily by being size discriminating to contaminants & particles. This type of element is designed to trap particles larger than the pores (voids) in the media itself. One result is that particles smaller than these pores tend to pass straight through the media unimpeded. For the purposes of this paper, this is defined as ‘discrimination by size’.

Size discrimination pic 1



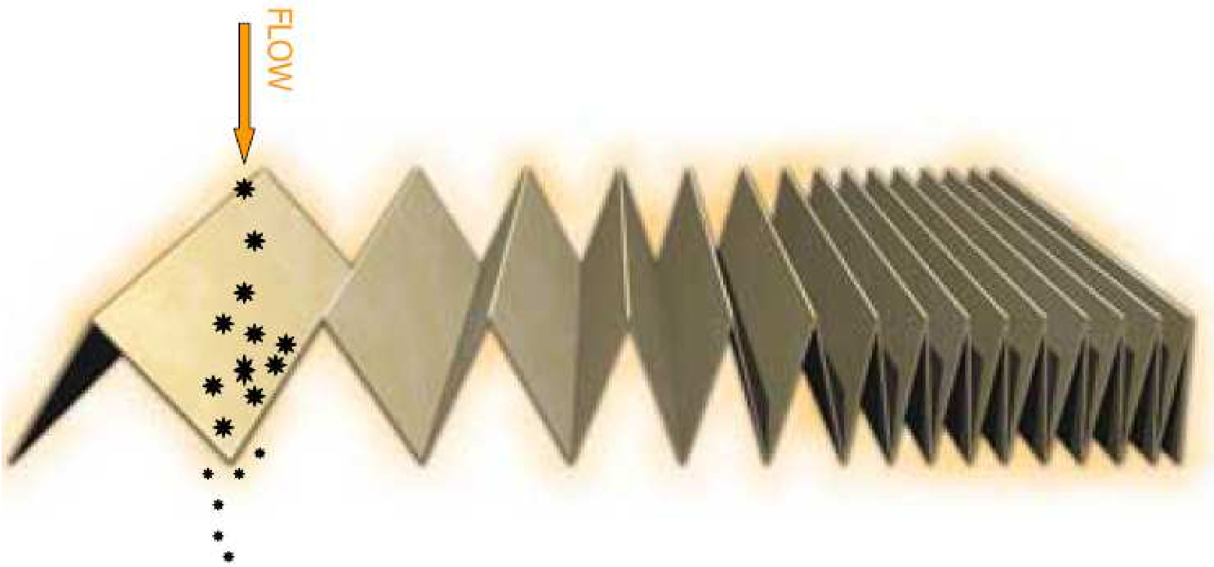


Figure 1: Simple performance description of a traditional barrier filter.

The above figure provides a graphical representation of the performance of a traditional barrier filter (conventional filtration) in terms of particulate size.

Within the fluid power industry and many other industries that utilize conventional filtration techniques and technologies there are some assumptions & practices that have been generally passed around for decades. Most of these assumptions deal with the performance of the conventional filter itself. Specifically that filtration performance within a real life system at the end user level, mirrors the performance of the same filtration inside a controlled laboratory environment. The important (incorrect) assumption in this case is that the two locations are treated as identical and mutually relevant. The standards generally portrayed important performance characteristics of a conventional filter are usually Beta Ratios and ISO Tests.

What started as a good idea, namely to provide a generic baseline to compare one filter element or screen against another, has evolved into a generally accepted measurement of system efficiency . Conventional filters have been continuously developed and redeveloped over the years to meet these standards (test parameters). The issue at hand is that in general, the tests are not truly representative of the real life environment in which these filters are applied.

ISO TEST BASICS

Within the laboratory environment, filter ISO testing is typically based on a percentage of contaminants captured under a steady state (constant) flow rate. The contaminant introduced is a standard ‘dust’ as defined within the ISO standard. The first issue to consider are the real life characteristics in hydraulic & fluid power systems.

ISO testing was developed in an attempt to quantify the performance characteristics of a filter on a hydraulic system on a power unit, under steady state operating conditions. This is important because a non-varying flow rate signifies that no valves, actuators, variable volume pumps or external loads are ever imparted on the hydraulic system.

Any end-user or designer of fluid power equipment knows that a real-life hydraulic system is anything but constant flow. Almost all industrial power units and mobile systems undergo massive variations in demand and flow.

This variation in flow rate has a remarkable effect on the performance of a conventional 10 micron absolute filter element (industry typical element). When the exact same filter elements are tested, one in a standard steady-state ISO test and another in the same test except with variable flow rates, the collection & retention efficiencies of the filter are affected dramatically. Figure 2 shows changes in flow rate as measured by changes in pressure across the element. The flow rate is varied approximately 30% every two minutes over the length of the test. This test is known as Dynamic Filter Efficiency (DFE).

At the 0:49 minute mark the filter again experiences a change in flow rate of approximately 30%. More specifically, this represents a reduction in flow rate as a real life system may experience with just the opening or closing of a valve. Figure 3 shows the effect of the change in flow rate on the filter elements ability to retain previously captured contaminant. The 0:49 minute mark in Figure 3 shows retention percentages as low as 18%. This is equivalent to the element emitting large and concentrated clouds of contaminant downstream of the filter and headlong into the valves, cylinders and pumps.

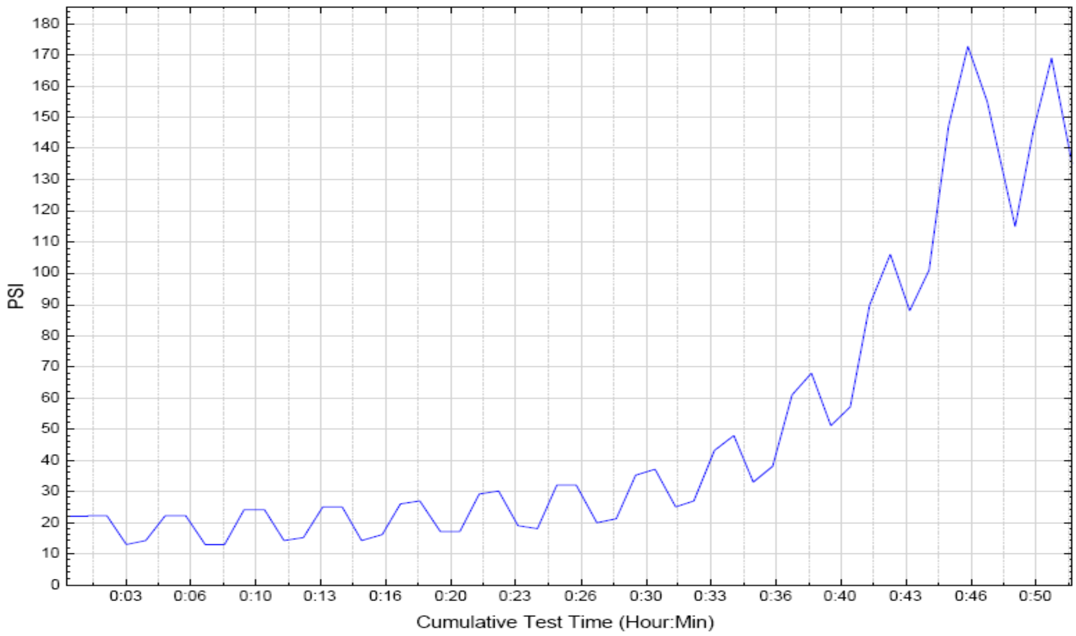


Figure 2: Filter Flow Variation Depicted by Changes in Pressure.

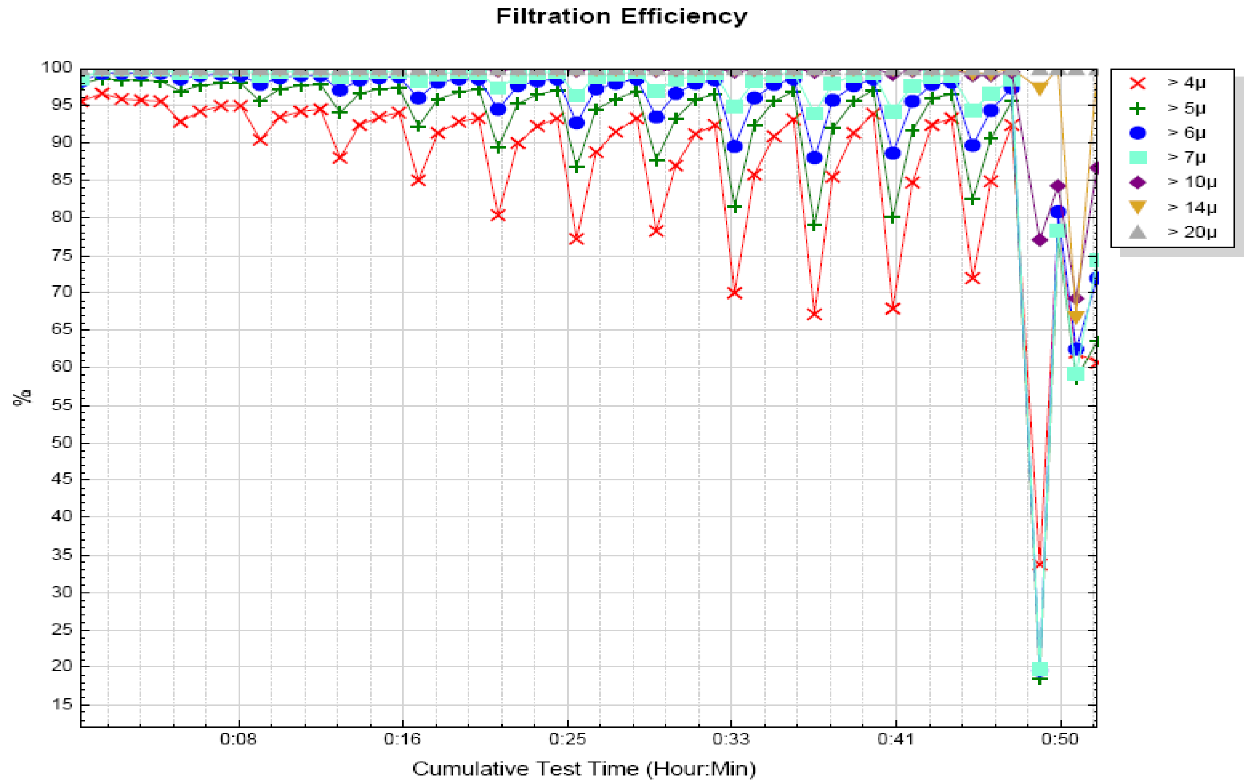


Figure 3: Filter Contaminant Retention Efficiency by Particulate Size.

Filter performance information provided by, Scientific Services Inc, *Cary, North Carolina 27519.*

If the flow is then varied from minimum to maximum (as in a mobile system) then the affect on 'filtration efficiency' & 'contaminant retention by the filter' is even more dramatic. This is one reason why for years hydraulic engineers and customers have been puzzled as to why seemingly clean (as far as the ISO rating goes) pieces of equipment fail to perform or fail on the jobsite without any apparent change in conditions.

LIMITATIONS WHEN SPECIFYING CONVENTIONAL FILTERS

Conventional filters require compromises and special considerations when being specified & fitted to fluid systems. The hydraulics engineer must take into consideration system conditions such as… flow direction, flow restriction, typical flow rates, pressure differential and by-pass requirements.

Let us not forget one of the biggest assumptions for system designers is that customers actually change the filter elements when the element reaches saturation. However, more often than generally acknowledged, this is not the case. This is especially true of mobile hydraulic equipment out on the jobsite. Often a filter goes unchanged because the job is behind schedule and the equipment is used right through the specified service interval.

All of the considerations briefly outlined above are taken in account by system designers when installing a conventional filter and yet the greatest threat to fluid power systems has not yet been addressed. The objective of this paper is not to make the case that conventional filters are not necessary or that they are worse than no filter at all. The objective is for the reader at this point in the paper to understand that conventional filters do have limitations in real life environments, and that viable complimentary solutions are available.

THE GREATEST THREAT TO FLUID POWER SYSTEMS

WHAT CAUSES FAILURES IN FLUID POWER SYSTEMS?

Apart from the build-up of excessive heat in fluid power systems, failures as a result of contamination are at the very top of any hydraulic engineers list of potential causes. More specifically, contaminants as hard as or harder than the material makeup of the system components themselves is the root cause of excessive wear. Essentially pieces of the system itself, in the form of contaminant come from one of the following three sources:

1) Built in during manufacture,
2) Generated during start up & break in,
3) Generated as part of general wear and tear over time and/or ingested.

80-90% of the products manufactured world-wide are manufactured from Carbon Steel. Therefore it will be no surprise that the vast majority of contamination built into a product/system at the point of manufacture is steel or iron.

During start up and break in, some of the components that are breaking in and being "worn in" will be steel on steel. A large portion of steel (ferrous) contaminant becomes suspended in fluids during this period. This is the reason fluid systems, from the engine and transmission in an automobile to the hydraulic system of an 'off highway' piece of mobile equipment, have their oil and filter changed as part of the break in procedure. This is a clear attempt to prevent premature wear, damage and failure caused by ferrous contaminant circulating in the fluid.

During the life cycle of any fluid power system ferrous contaminants are present and are the catalyst for the "chain reaction of wear" (and cause of imminent catastrophic failure) . The "chain reaction of wear" is described as a few particles, circulating in the system and generating additional particles and these additional particles along with the original particles generating even more particles at an exponential rate. This condition is exactly why oil analysis laboratories world wide use ferrography when performing oil sample testing as part of a trend analysis program. The laboratories understand that it is the ferrous particles that are the greatest threat to a real life hydraulic system in the field and the mere presence of these particles could spell trouble in the form of 'decreased' performance and 'increased' maintenance costs.

FERROUS PARTICLES: THE GREATEST THREAT

Almost all engineers will agree that the mere suggestion of ferrous particles in a fluid power system presents a major issue in terms of system design and reliability. Historically though, many engineers have focused on filtration as an auxiliary component in the design of hydraulic systems. Even further removed from thought is the actual material composition and size of the contaminants. This historical lack of priority and focus on system filtration, coupled with an absence of an effective and efficient technology to address the situation, means little has been done historically to address this long standing problem.

Ferrous particles are the “Smallest”, “Hardest” & “Sharpest” contaminants present in hydraulic systems and they can pass straight through conventional filter elements. This is usually due to two simple reasons: 1) Ferrous particles are very small,
2) Conventional hydraulic filter elements (and screens) are usually higher in their micron rating, than the engineer would like them to be when considering real life and practical hydraulic system designs.

First, it is no surprise that ferrous particles naturally come from ferrous components. The component surfaces of ferrous (steel or iron) materials are very hard. Ferrous is so hard in fact that in Rockwell Hardness Tests steel and iron utilize a completely different scale than aluminium and brass alloys. The inherent hardness of steel means that steel (ferrous) surfaces do not give up pieces of themselves easily. This means that high carbon steel particles are actually torn from these surfaces in only very tiny pieces.

These ferrous particles are typically under 15 microns in size and most are in the 5-10 micron range. The particles are not only very small, but a result of being torn from a hard surface they are also very sharp and angular. This means that by their very nature, ferrous particles are generated in the perfect size, shape and hardness to generate more ferrous particles and wear metals. These wear metals are typically brass and aluminium from other hydraulic system components.

Figures 4, 5 and 6 are electron microscope images of ferrous particles removed from real life hydraulic systems in the field. Figure 6 depicts a scale of 10 microns (noted by the white horizontal bar). Note the quantity of particles in the 15 microns size and less. It is a vast majority, if not all of the particles present. The images were processed by the *Department of Science and Engineering at Liverpool John Moors University.*

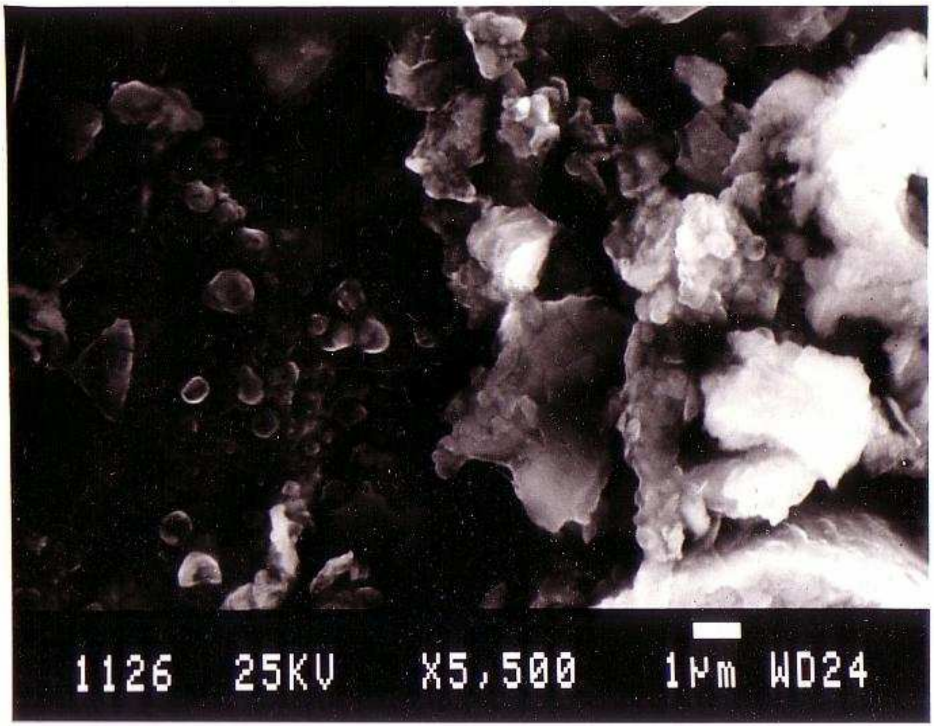


Figure 4: High Carbon Steel Particles, 1 micron scale.

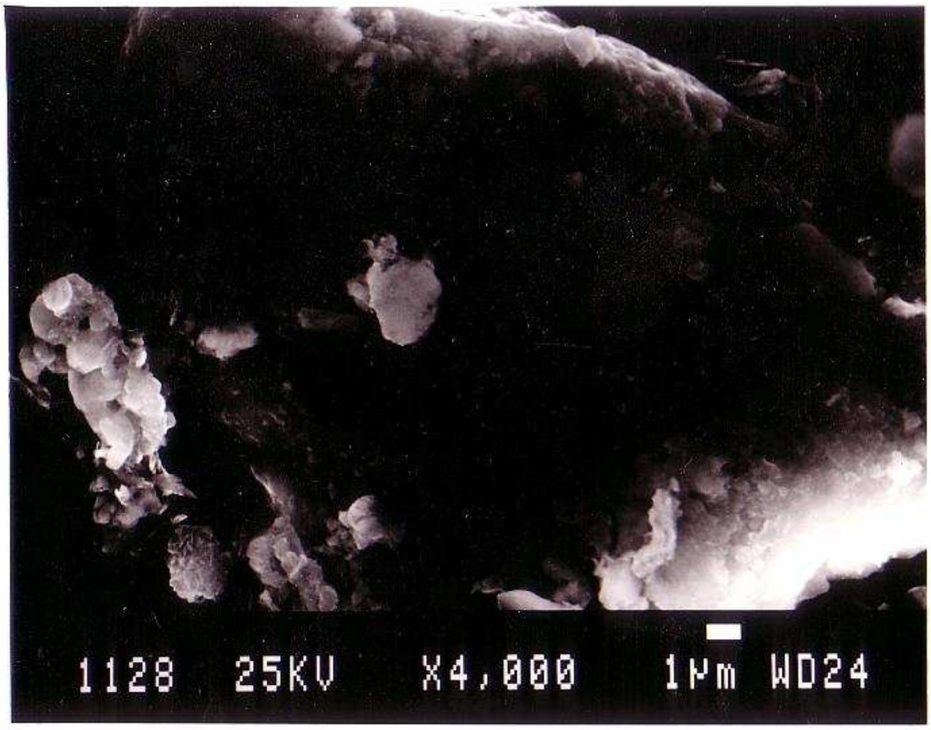


Figure 5: High Carbon Steel Particles, 1 micron scale.

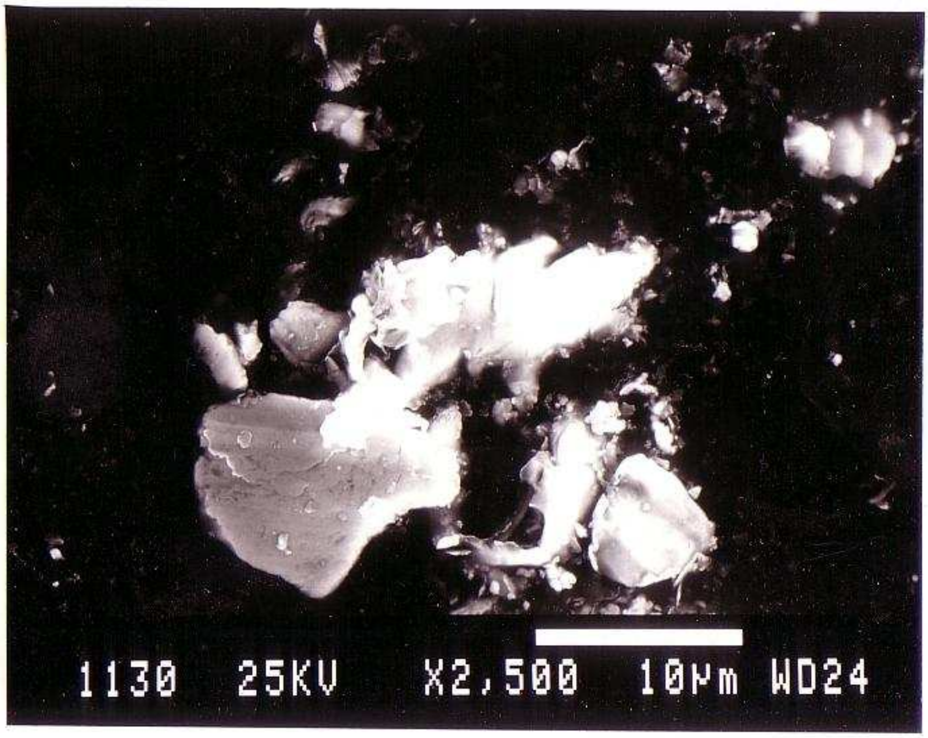


Figure 6: High Carbon Steel Particles, 10 micron scale.

The second reason is a practical result of simple physics, engineering design and cost. Most hydraulic system filter elements, especially in mobile equipment, tend to be 10 micron absolute in their filter rating. The term 'absolute' has limited scientific relevancy in this case as the filter could allow particles well above and certainly below 10 microns to pass through without impeding the particles movement. It is one of the reasons that filters are rated on their ability to capture contaminant under 'multi-pass' conditions rather than solely 'single-pass'.

Limitations in hydraulic system design (cost versus performance) arise from the maximum allowable pressure drop across a filter element and the need to maintain certain flow rates. Every engineer would like to use a 1 micron absolute rated filter element in their system, if only the selection didn't require a large increase in cost, complexity to the overall design, and a large space claim requirement.

Since most ferrous particles are in the 5-10 micron range and most filter elements used today are 10 micron absolute, this means that many of the ferrous particles are left unchecked to freely circulate throughout the hydraulic system. Conventional filter elements can conceivably remove particles of say paint, o-ring, dust and wear metals because these are generally ductile and therefore larger in size than ferrous particles. This leaves almost every piece of high carbon steel under or near 10 microns in size to freely circulate around the system.

As these ferrous particles circulate around the hydraulic system time and time again, they generate more contamination & other particles in the process described previously as the 'chain reaction of wear'. The particles created are either additional ferrous particulate (only ferrous particles can create other ferrous particles) or they are a combination of ferrous and non-ferrous wear metal particles.

When this condition is considered along with the ‘wash through’ or retention efficiency condition highlighted in the data provided by SSI’s DFE analysis, then the impact that ferrous contamination has on a system is detrimental and obvious. This is why every hydraulic engineer must consider not just the size of the contaminants present in the system, but the inherent threat level posed by each particle type and size.

INDUSTRY’S ATTEMPT TO DEAL WITH THE GREATEST THREAT

Historically, the OEM’s and end users of hydraulic systems have recognized the ferrous problem and attempted to deal with it by using one form of magnetic device or another. Attempts to deal with ferrous contaminants in fluids have typically resulted in the addition of some form of magnet inserted into a hydraulic reservoir or even stuck to the inside or outside of the filter housing. Some manufacturers have even inserted magnets into the filter elements themselves. Figure 7 depicts “magnetic filters” in various forms.

Attempts to deal with this historical problem are represented below in Figure 7. These products serve to demonstrate that a problem has existed and has been identified for many years. The very presence of magnetic devices in hydraulic systems serves to highlight the historical limitations of conventional filtration. Even the most sophisticated hydraulic systems, aircraft and aviation hydraulics, use some form of magnetic filter.

Magnetic Drain Plug	**External Filter Pad**	**Magnetic Rod Insert**
		

Figure 7: Various Traditional Magnetic Filter Devices

For example, take the application of a simple magnetic drain plug. Following routine equipment service or a system failure, when the magnetic drain plug is removed, it always has ferrous contamination ‘stuck’ to the magnet.

Historically, magnetic filter designs also fail to meet the specific and demanding requirements of a fluid power environment. Quite simply, they are either random in nature like, “the sump plug” (just radiating and diffusing magnetic flux into a random space) or they are placed directly in often turbulent fluid flow and suffer wash off of contaminant as it builds on the magnet surface.

The issue is one of simple physics, namely that magnetic energy drops of in strength by the inverse of the cube, over distance. Basically, this means that contaminant has to be very very close to the magnetic source to be attracted and removed. Figure 8 depicts the relationship graphically.

This is not just about removal of contaminant; it is about retention of the contamination once it has been removed from the hydraulic fluid. Just as conventional filters have issues with particulate retention as shown in Figure 3, so do standard magnets.

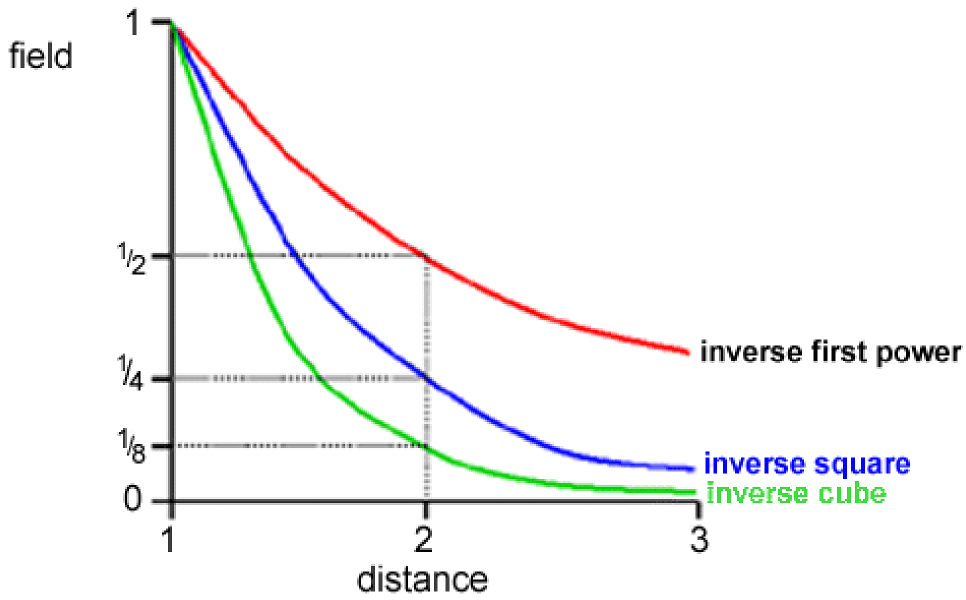


Figure 8: Magnetic Energy Dissipation Over Distance

Magnetic drain plugs and similar magnetic devices cause many more problems than they actually solve because they suffer from wash off of particles. The contaminant is only influenced by a diffused magnetic flux as there is no concentration or forced direction of the energy. This means that as more particles come in contact with the magnet, the more the particles are located further away from the magnet (or energy source) and as the contaminant grows away from the energy source it eventually washes off.

Once washed from the magnet, the particles do not drop back into suspension within the hydraulic fluid. Since the particles were exposed to a magnetic field, they remain as a clump, weakly magnetised together. This reality is depicted in Figure 9 and Figure 10 below, and the first component this concentration of high carbon steel reaches often sufferers catastrophic failure, for obvious reasons. This is why catastrophic failures of single components occur in systems that appear to be in perfect condition previously.

Engineers who inspect the components after these system failures see that one component catastrophically failed, while the rest of the components are to specification and within manufacturer's tolerance. When the failed component is inspected, typically high carbon steel contaminant can be seen imbedded in the softer wear metals close to where the fluid is introduced to the component.

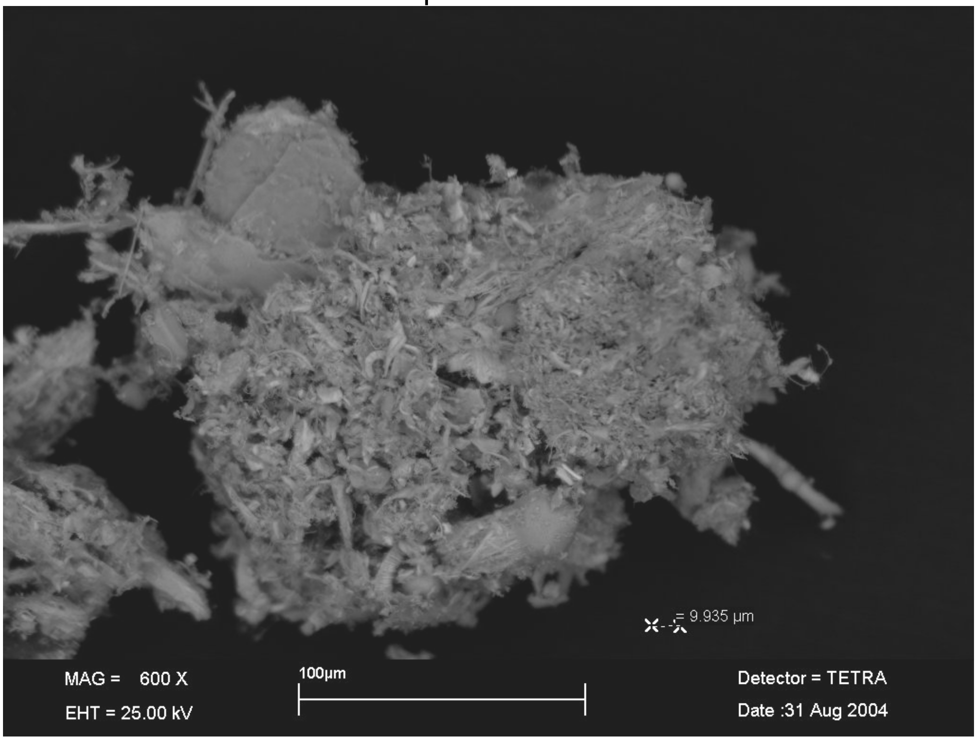


Figure 9: Magnetized Clump of Under 10 Micron Ferrous Particulate

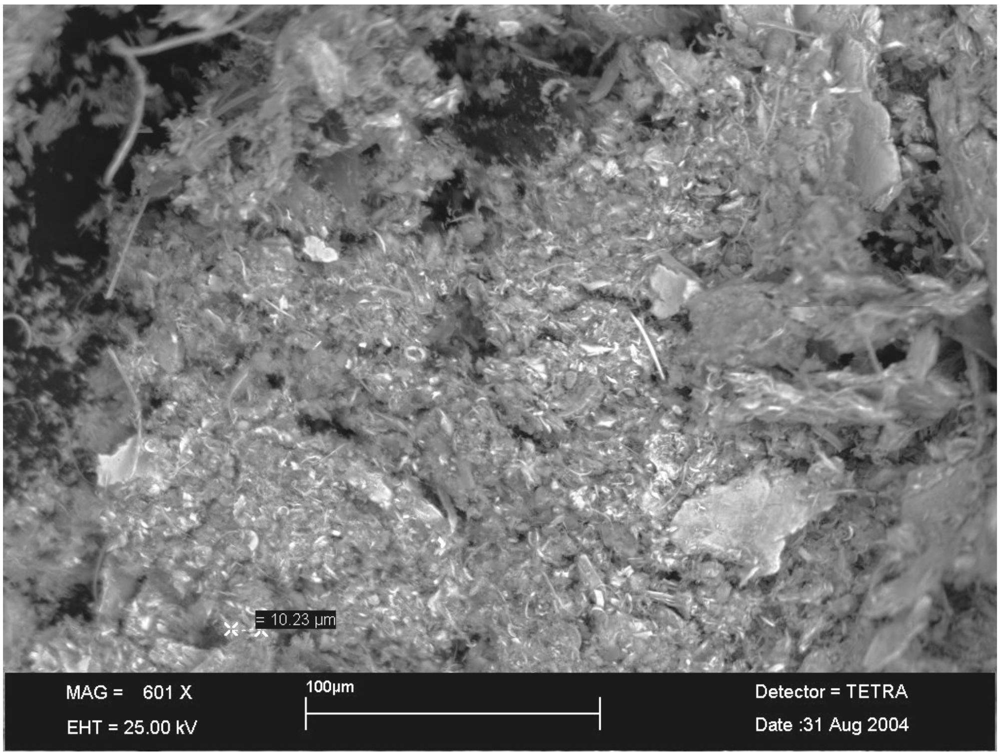


Figure 10: Magnetized Clump of Under 10 Micron Ferrous Particulate

Analysis and Micrograph images of contaminant provided by Rob Chapman of QinetiQ *'Research division for the UK Armed Forces',* Fuels & Lubricants Centre, Pyestock UK The observance of magnetic sump plug 'wash off' creates problems for hydraulic systems. If this observation is coupled with the data from Dynamic Filter Efficiency testing detailing the wash off or perhaps best described as *wash though* of contaminant in conventional hydraulic filters, this highlights a longstanding problem and provides an interesting challenge when developing a solution.

THE OPTIMUM FORM OF THE SOLUTION

Given the problems caused by ferrous contaminants in hydraulic systems it made sense to apply some advanced design techniques to a new type of filtration technology. To resolve this historical filtration problem, the weaknesses and strengths of existing filter products and technologies available to the hydraulic system engineer, builder & end user were assessed. Figure 11 shows both the positive and the negative attributes of both the conventional filter element and magnetic device filtration.

CONVENTIONAL FILTRATION ELEMENTS (Positives +)	CONVENTIONAL FILTRATION ELEMENTS (Negatives -)
+ Systematic, filtration sees all the fluid and all the contaminant with each pass. + Good retention @ low & steady state flows + Efficient contaminant removal (based upon particulate size)	- Flow Restrictive - Creates a pressure drop that increases with use - Size discriminate - Relatively low capacity for contamination, per a given volume
TRADITIONAL MAGNETIC PRODUCTS & DESIGNS (Positives +)	**TRADITIONAL MAGNETIC PRODUCTS & DESIGNS (Negatives -)**
+ Non restrictive to fluid flow + No Pressure Drop + Non size discriminate, targets the worst threat	- Poor retention of captured particles, wash off - Non systematic, random removal of particulates

Figure 11: Advantages Versus Disadvantages Of Current Technologies

The solution to this historical filtration problem should have all the features in the positive column without any of the negatives to be an effective solution. Using these attributes as a definitive guide, a technology has been developed to effectively eliminate the ferrous problem observed in real life hydraulic systems in the field.

THE SOLUTION TO THE FERROUS THREAT

CORE TECHNOLOGY OVERVIEW

The technical solution to the historic filtration problems outlined in Figure 11 is in the form of a MAGnetic Oil Module . The Core Technology was developed, in partnership with the Formula 1 Racing industry. Many technical features and ideas were honed and tested on the race track in some of the most gruelling and performance demanding environments, in the development of Core Technology.

The result was a very simple, yet effective ‘filtration’ solution. The basic form of the technology consists of a permanent power source provided by a magnet that is sandwiched between two carbon steel plates. Figure 12 below shows a graphical representation of the basic Core Technology.

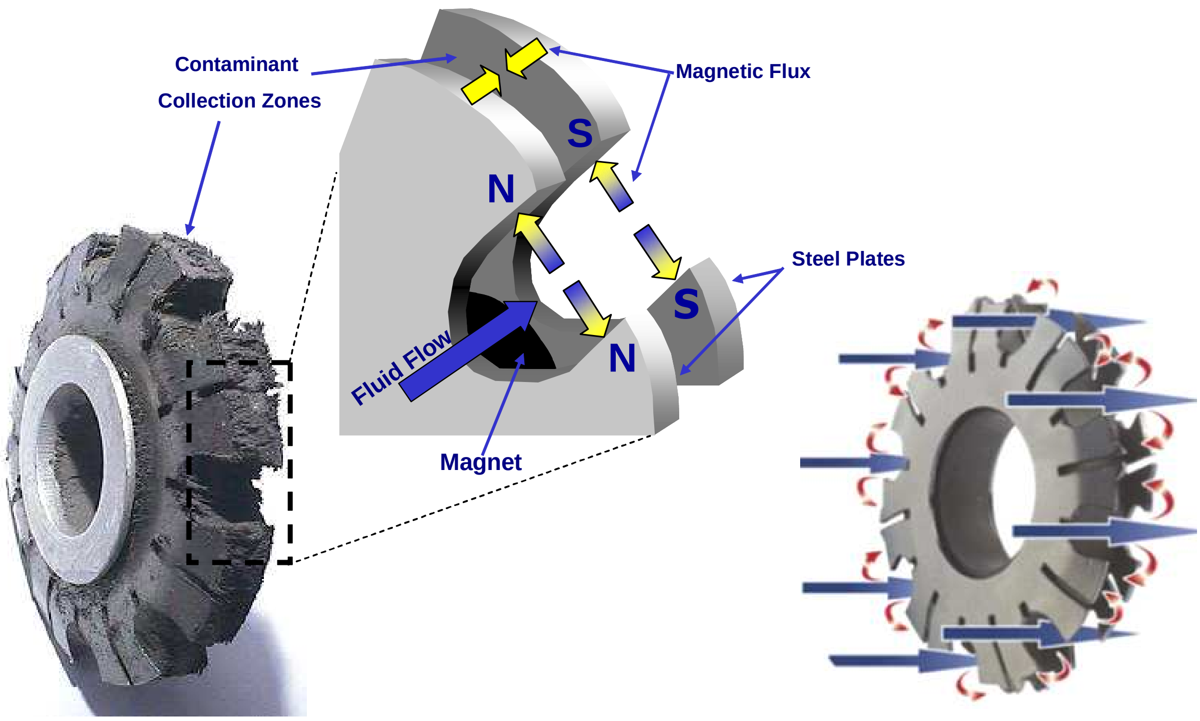


Figure 12:– The Basic Core Element

The steel plates are used for three reasons. The first is to intensify the magnetic flux field. Steel transmits magnetic flux up to 15 times more efficiently than the magnet itself. This is the underlying principal of why laminations of steel are used in armatures of generators and motors. The second reason is to project & focus this increase in energy directly into the fluid flow. Finally, the steel plates provide a very secure 'trap' to hold contaminant out of the fluid flow. These 'traps' prevent captured contaminant from being washed back into the hydraulic system.

TECHNOLOGY FORM & FUNCTION

Some very important design features of the core technology ensure that all of the positive aspects of current conventional filter element and magnetic solution designs are featured, but without any of the negative aspects. These features can be reviewed in Figure 11 above.

The first important feature relates to the incorporation of fluid flow channels cut directly out of the steel plates (i.e. motor armature). The design of the flow channels ensure that the total cross sectional area of the fluid flow channels exceeds the cross sectional flow area of any feed pipe or hose delivering fluid to the core by up to 15%. Figure 13 graphically depicts the flow channel cut outs and the flow areas for the hydraulic fluid.

This means that the cores deliver a 'minimal' pressure differential when both empty and full of contaminant. The characteristic of minimal pressure differential permits this solution to be located anywhere in the hydraulic system and in a 'full fluid flow' capacity. This even allows placement of a magnetic core before a sensitive variable displacement pump. These cores are systematic in filtration capability and see all of the fluid flow and all of the system contaminant. This is one of the critical features depicted in Figure 11.

Figure 14 are tabular results of the core's basic performance conducted by a leading independent hydraulic specialist. The test was conducted on the suction side of the pump with the core located inside of the reservoir. The first test compares a core capable of a flow equal to 2 inch schedule 40 pipe flow with negligible pressure. The net pressure differential was 0.126 psi.

The test was then repeated using the same core; the only difference was that the filter was full of contaminant. The filter held approximately one half pound of contaminant. The net pressure differential between a clean core and a full core was 0.02 psi.

Figure 13: Core Element Flow Channels

Figure 14: Differential Pressure Testing of the Core Technology

The second important feature of the core technology is another by-product of creating the fluid flow channels as depicted in Figure 13 with the large horizontal arrows.

The remaining steel to either side of the flow channel create a pair of containment retention zones or traps. The containment zones are three dimensional in design and they typically hold up to 40 times or more of contaminant than a similarly sized conventional filter.

Figure 15: 3-Dimensional Containment Zones (Traps)

The particles in these containment zones are held outside and away from the flow path of the hydraulic fluid. The top and bottom steel plate (flux plate) surrounding the containment zone forms a physical barrier for the contaminant, thus preventing wash-off of the trapped contaminant back into the hydraulic fluid. Figure 15 and Figure 16 are close-up views of heavily contaminated containment zones. Notice how the flow paths remain clear of particles while the containment zones are packed full of particles.

Captured particles become firmly contained within the containment zones, behind the flux plates, due to the refraction of the hydraulic fluid as it passes through the flow channel. This observation was first made in a real customer application. Figure 17 shows the resulting contamination and the actual refraction and subsequent compression of the contaminant fully behind the flux plates and out of the fluid flow path. The core was installed in a Moog valve application. All of the contaminant contained in the core is 5 microns or less in size.

This observation was then modelled and validated by Liverpool John Moors University using ANSYS Finite Element Software. Figures 18 and 19 depict the model created to validate the refraction observation. The model shows the effects of refraction as it 'pushes' contaminant behind the flux plates. One final detail is the areas of low turbulence behind the flux plates. The areas of refraction and low turbulence are depicted by the arrows of varying length. This is just another fluid dynamic condition that helps to create the perfect containment field located behind the flux plates.

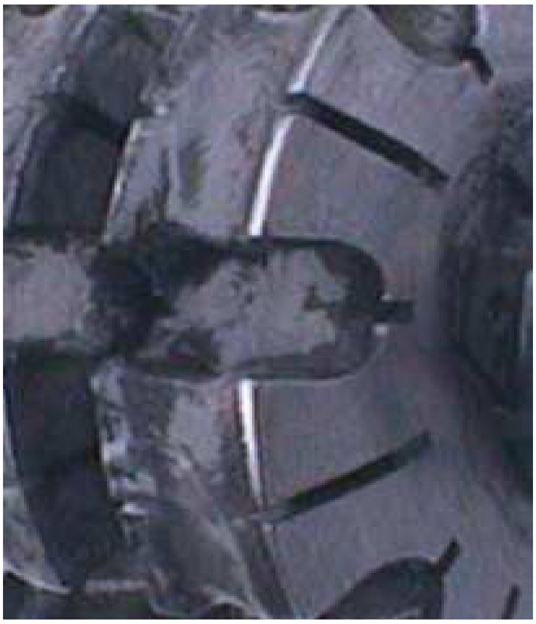


Figure 16: Containment Zones With Contaminant

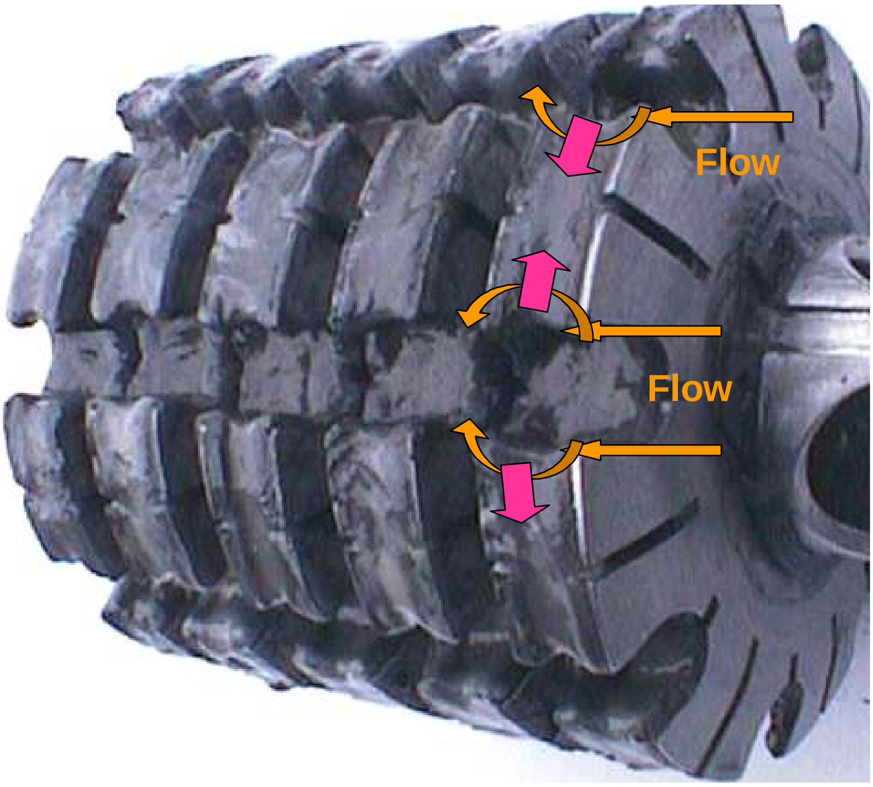


Figure 17: Refraction Of Fluid Through Flow Channels

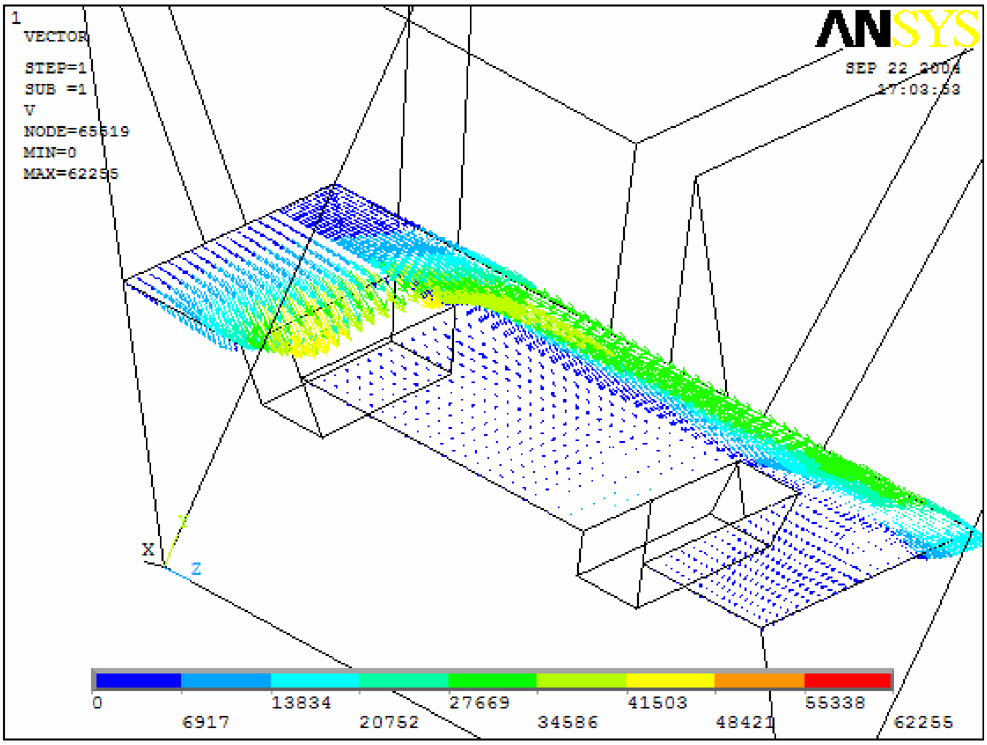


Figure 18: Modeling of Refraction And Areas of Low Turbulence

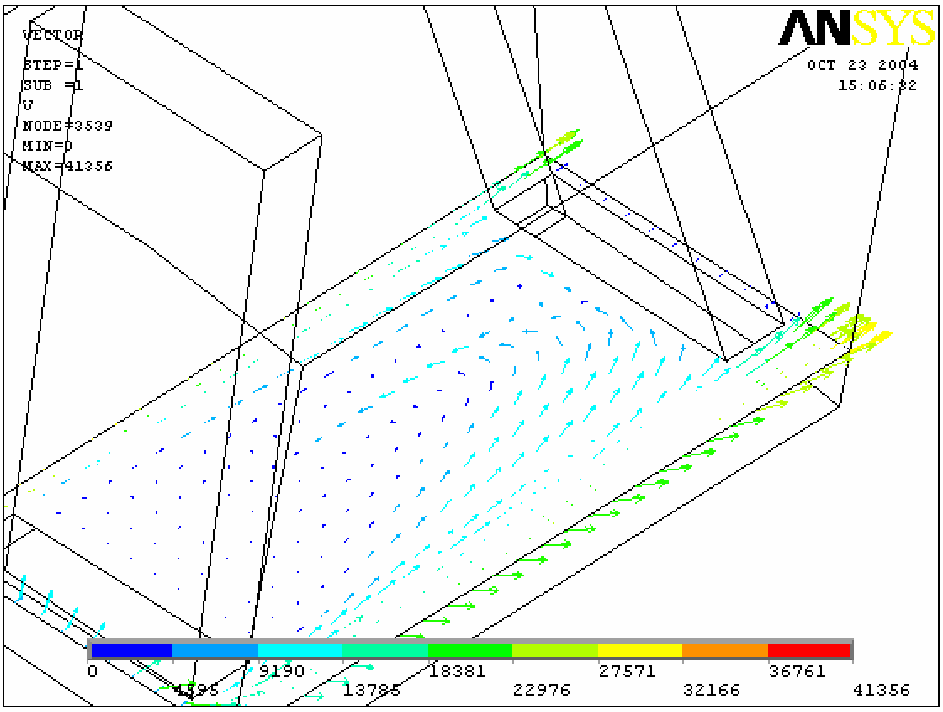


Figure 19: Modeling of Refraction And Areas of Low Turbulence

The magnetic cores also do not discriminate based on the size of the particulate. In real life fluid power situations, core units have been observed to remove particles as small as 0.07 microns in size and to remove up to 97% of the particles in a single pass through the core. In other configurations and situations cores can approach closer to 100% efficiency on a single pass through the filter.

Figure 20 is an example of staged contamination build-up as a direct result of high single pass efficiency. Once an individual Core Element is full of contaminant, the next core down stream will start to fill. This process is repeated until the all 5 cores are full of contaminant. The filter core in Figure 20 is a little more than 4/5 of its capacity.

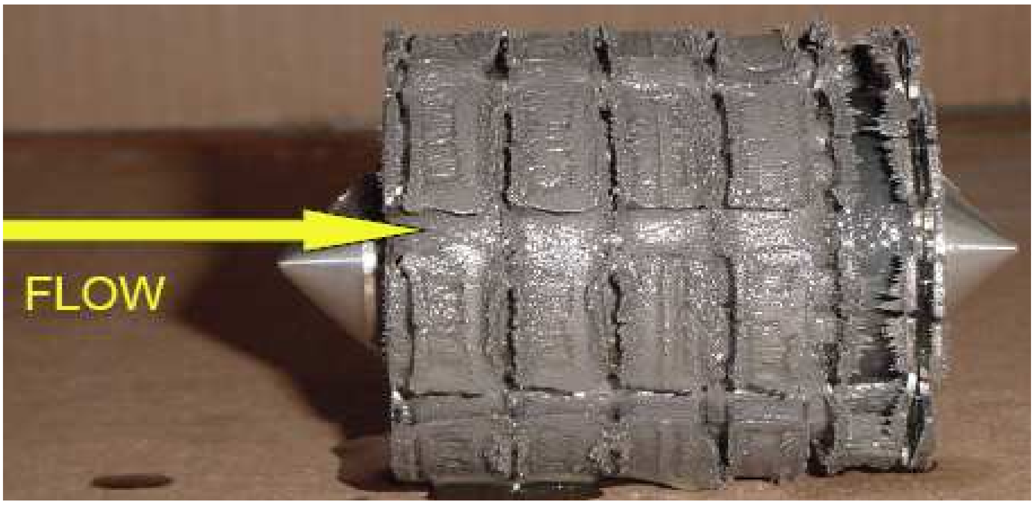


Figure 20: Single Pass Efficiency Of 4/5 Full Core

A completely full Core is depicted in Figure 21. In this case, the filter is full with rust from a cooling water application at a nuclear power plant. Notice that the flow channels remain free and clear of contaminate.

Figure 21: Full Core with Clear Flow Channels

Not only is the core technology single pass efficient, (up to 97% per individual core, down to less than 1 micron), its efficiency has been shown to increase with fluid velocity. This is thought to be partly as a result of the refraction described earlier, The refraction of the fluid brings contaminant even closer to the higher energy field behind the flux plates.

The phenomenon of core efficiency increasing with velocity was observed in independent testing carried out at Loughborough University in the UK, and is represented in the following quotation:

“It is concluded that, theoretically, the higher flow rate should reduce the separation efficiency because of the rise in hydrodynamic drag. However, in this experiment, the increase of the fluid’s flow rate also increases separation efficiency. This is believed to be as a result of the unique design of the core which prevents iron particles trapped in its collection zone from being washed-off by fluid. This characteristic is very interesting as it appears to be the same in every experimental condition”. This conclusion and the corresponding results are from an independent test carried out at The chair of the Filtration Society at Loughborough University UK’.

The final unique design characteristic of the cores is in the very arrangement of the flux plates between core elements when arranged in a core stack. This unique feature ensures that no magnetic energy is wasted because the arrangement drives surplus energy within the steel flux plates to the cut edges of the flow paths. This is accomplished by arranging the individual cores in repulsion. Similar magnetic poles act in repulsion (i.e. North and North) and Figure 22 provides a 3-dimensional representation of the core configuration.

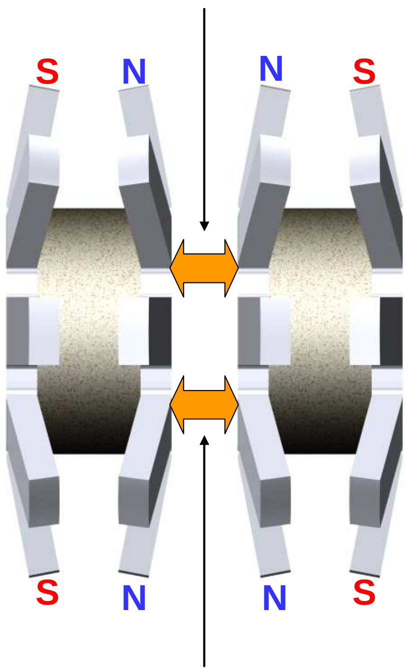


Figure 22: Arrangement Of Multiple Core Elements

The features on the preceding pages are the key to the core technology's superb collection and retention characteristics. Simply the magnetic cores remove the most damaging contamination in a system down to sub micron levels quickly, efficiently and without wash-off of captured particles or fluid restriction.

CORE TESTING RESULTS

Core enhanced hydraulic and lubrication filters have unique characteristics in their unique design and in their performance in laboratory tests, but what happens in the real world on a customer's machine? The core technology was included on a brand new hydraulic power unit straight on the factory floor of a world leader in the production of large industrial, hydraulic power units based in Germany. Before installation of the core the hydraulic power unit was repeatedly flushed with 2 micron absolute filtration on a flushing rig.

A core was then installed *before* a large variable displacement, axial piston pump. The core was the only filtration remaining on the hydraulic power unit. The hydraulic power unit was then filled with clean hydraulic fluid and a sample of the hydraulic oil was taken. Figure 23 clearly shows the results of this sample under the column 'Hydraulic Oil Sample 1, System Commissioning, Clean Oil'. The oil added to the hydraulic power unit was 'cleaned' by an independent laboratory.

Next the hydraulic power unit went through a conditioning and break in cycle for approximately one months time. A second hydraulic oil sample was drawn. Figure 23 shows the results under 'Hydraulic Oil Sample 2, One Month Later, 3/28/2006'. Again, the oil sample even after circulating in the hydraulic power unit was still very clean. On the surface, this would be as expected. i.e. First flush a hydraulic unit by using a very low micron rated external filtration system, add fresh clean oil and the system can be considered clean.

In reality, this is not the case. The core was then removed and sent to the external laboratory for analysis. The results are shown in Figure 23 under the column 'Core sample, 3/28/2006'. Even though the oil was shown to be clean, significant amounts of contaminant were still present in the hydraulic system hidden away in various components from the date of manufacture. If left unchecked, these ferrous and non-ferrous contaminants would have passed straight into the pump and would have been circulated around the system. This is a real life example of Stopping the Chain Reaction of Wear dead in its tracks.

		Hydraulic Oil Sample 1 System Commissioning "Clean Oil"	*Hydraulic Oil Sample 2* One Month Later	Filter Sample Analysis of Contaminant Inside Core
		3/1/2006	**3/28/2006**	**3/28/2006**
Iron	**Fe [ppm]**	**0**	**0**	**1501**
Chromium	**Cr [ppm]**	**0**	**0**	**7**
Tin	**Sn [ppm]**	**0**	**0**	**13**
Aluminum	**Al [ppm]**	**1**	**1**	**35**
Nickel	**Ni [ppm]**	**1**	**0**	**2**
Copper	**Cu [ppm]**	**5**	**6**	**14**
Lead	**Pb [ppm]**	**0**	**4**	**1**
Molybdenum	**Mb [ppm]**	**0**	**0**	**0**
Silicon	**Si [ppm]**	**0**	**0**	**66**
Potassium	**K [ppm]**	**0**	**0**	**71**
Sodium	**Na [ppm]**	**3**	**2**	**15**

Figure 23: Performance Testing – Hydraulic Power Unit

An astute observer would now ask himself or herself, "How did the core remove non ferrous particles"? Much thought has been given to this perplexing problem over time. It was only after many observations in real life hydraulic applications in the field did the answers begin to surface. One recent hydraulic equipment user used the core technology to filter the case drain on an axial piston pump that was heavily worn and in its last stages of life/service.

After removing the core for inspection (See Figure 24), both ferrous and non ferrous particles were found within the core containment zones. Upon closer inspection, many of the hard ferrous particles were found to be imbedded into the ductile bronze material. This happens as a result of hard aggressive ferrous contaminants tearing at the bronze (and other non magnetic & non ferrous materials) as they flow between working parts & surfaces, the softer sacrificial materials (wear metals, non ferrous) then become swaged onto the ferrous particles.

In addition, ferromagnetic particles are elements (e.g. Nickel, iron, cobalt) that can be strongly influenced by a magnetic field. Magnesium and aluminum are paramagnetic materials whereby they have magnetic moments, the effect while observable, is much smaller than with ferromagnetic materials and is proportional to the magnetic field. Finally, copper and lead (i.e. bronze) are diamagnetic materials and the effect of a magnetic field is small, but exists nonetheless.

This highlights another logical and interesting, yet simple philosophy. By removing the hard ferrous contamination from a system in a highly efficient manner, this has a massive positive impact on the generation of other non ferrous contaminants that are typically found in hydraulic fluid systems. i.e. 'Remove the catalyst' and you arrest the "Chain Reaction of Wear".

The combination of both a ferrous and non ferrous particle supports two conclusions:

1) The hard, sharp steel particles generate the soft wear metals during the Chain Reaction of Wear Process.

2) When the ferrous particles pass through the Core and are removed, they also naturally bring the non ferrous particles that remain attached.

Figure 24: Core With Ferrous and Non Ferrous Contaminants

A final application shows cores stopping the chain reaction of wear and removing both ferrous and non ferrous contamination. Figure 25 graphically shows the oil analysis results after the installation of a core on the lubrication circuit of a large gearbox (transmission) on 11/21/00. The horizontal axis is time and the vertical axis is Parts Per Million (PPM).

The magnetic core removed the ferrous particles which stopped the generation of additional ferrous particles and significantly reduced the generation of non ferrous particles. Mainly the other particles in the system were soot, copper and aluminum. The soot was removed because it coated the ferrous particles and the copper and aluminum were imbedded with ferrous particles in a bi-metal configuration.

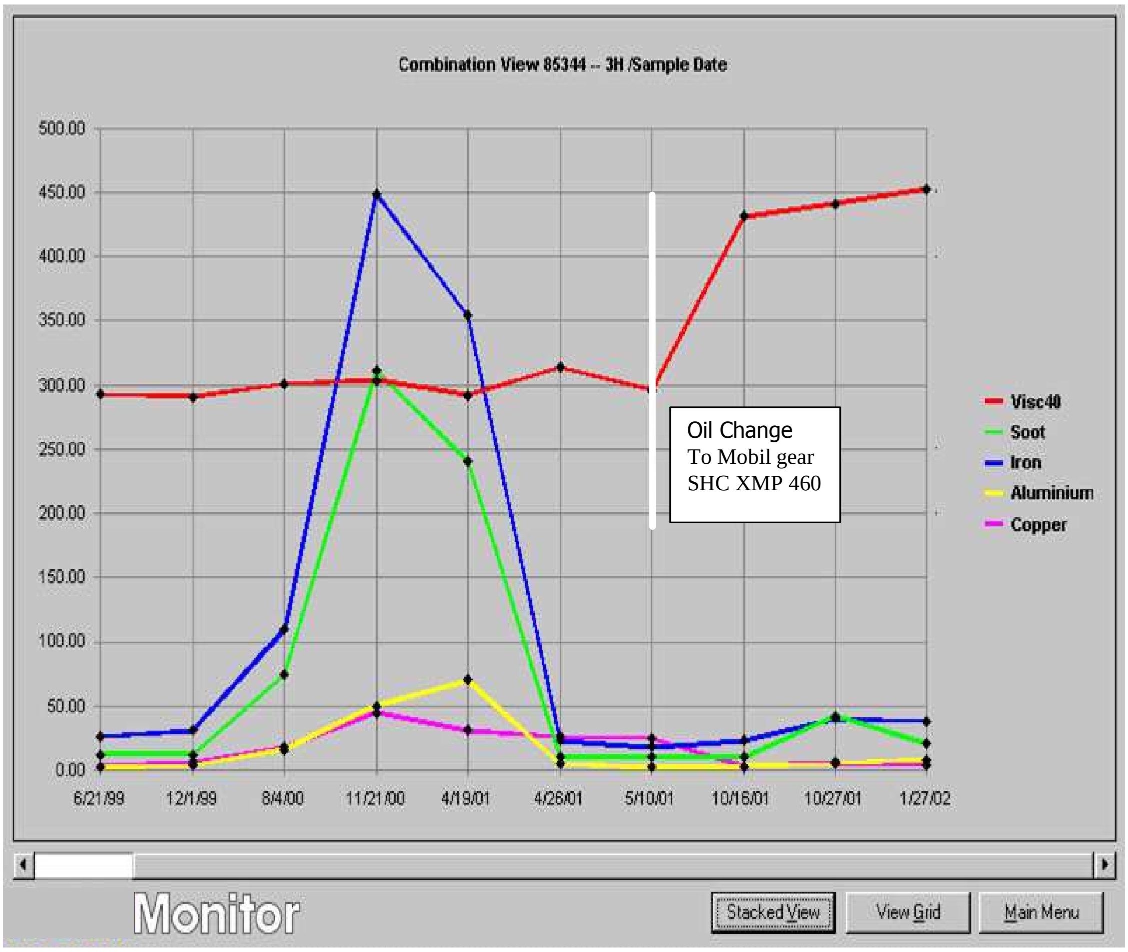


Figure 25: Gearbox Oil Analysis Results Over Time

Reducing the contamination level of the ferrous particles allow the shaft seals to perform at a higher level. This prevented the ingestion of even more soot. This is not just contamination removal on a highly efficient level, but control of the generation of other contaminants.

The result of efficiently removing contamination is readily seen in this example. The customer was experiencing 3-4 gearbox failures per year. Since the installation of the core technology on all of the customer's gearboxes the yearly gearbox failures have reduced to zero.

REAL LIFE BENEFITS OF USING MAGNETIC CORE TECHNOLOGY

BENEFITS TO BETTER DESIGN

Core Technology has been thoroughly documented and vetted with a number of large Mobile Equipment Manufacturers (OEM) and End Users of OEM Equipment. The case studies have shown that efficiently removing the worst threat to a hydraulic system (ferrous), at a strategic location in the system, can have a dramatic effect, on performance, reliability and availability of that system.

Access to these real life test facilities, allowed the designer to fine tune the products design, and demonstrate that the product design was appropriate in the application. This meant that the product solved an existing problem and delivered cost benefits to the end user. These experiences allowed the company to optimise the technology in its design, form and function.

By understanding the core's performance in each type of application and location within the hydraulic circuit, specific design criteria where laid down in the form of product development formulas. These formulas provide critical design criteria to ensure that a unit specified for a given application will deliver maximum performance in terms of particle removal and retention.

When considering the design options and perhaps the criteria imposed by a unique fluid power system or a large OEM application, factors such as the following are taken into account:

1) Magnet versus Flux Plate Mass Ratios.
2) Flux Plate and Magnet Surface Contact Area.
3) Cross Sectional Area of Flow
4) Contaminant Capacity
5) Overall First Pass Efficiency

All the factors are vital to maximising the performance of the core technology in a given application and all can vary from one design to another.

BENEFIT TO OEMs AND END-USERS

The first major design milestone came as a result of working very closely with a large Tier 1 manufacturer of off-highway mobile equipment. The OEM was looking for a way to protect their variable displacement, axial piston pumps during the program's proving ground test phase. The OEM was experiencing unusual amounts of failures at the time as these pumps were very sensitive to contamination.

Figure 26: Tier 1 OEM Test of Pre-Pump Filter

The pumps utilized on this particular vehicle were Bosch Rexroth A10 models. The unit designed for this application was an early prototype of the pre-pump suction filter . Figure 29 shows an external view of the ‘magnetic suction strainer’ on the left. The right image is a real sample of contamination captured during 1250 hours of testing. The amount of contamination captured in the unit was 4.75 grams.

Another Tier 1 OEM was targeted to test design criteria for lubrication circuits on mobile equipment. It was determined that application of this technology was thought to have increased filtration capability due to its ability to efficiently filter heavy gear oils and even grease.

Figure 27: Transmission Suction Strainer Replacement Test (Pre-Pump)

The unit was designed to fit within the space envelope of the existing suction strainer. The left most image in Figure 30 shows the suction strainer unit design. The unit is located inside the removable suction strainer housing for ease of retrofit.

The initial test machine completed over 759 hours of aggressive proving grounds testing and run-time. The visual results are clearly seen in the right most image of Figure 30. The contaminated Core contained over 20 grams of steel and iron particles. The most interesting result was that all of the contaminant was under 50 microns in size, the original mesh suction strainer that unit replaced would have permitted all of this steel to pass straight through!

The success of these tests influenced the decision to further validate the designs within the off-highway and mobile equipment sector. It was important to demonstrate that this emerging technology could prove its applicability, suitability and its performance in terms of delivering real benefit to the end user.

By targeting known and well established problems experienced by the end user, it was determined that the core technology was able to deliver benefits in the form of:

1) Lower Maintenance & Warranty Costs
2) Longer Hydraulic and Lubricating Fluid Life
3) Extended ‘Conventional Filter’ Life,
4) Longer Equipment Service Life
5) Increased Equipment Availability

CONCLUSION

By isolating and removing the most damaging contaminant to a fluid power system, dramatic improvements in the reliability and performance of that system are achievable.

Fluid system cleanliness has evolved from the premise of removing contaminant from fluids by particle size. It has been this way for some 70 years since Purolator invented the felt filter for engine oil. The absence of an efficient technology to address the real problem has meant that the industry as a whole has had to rely on existing filter technology to provide all of the answers. Conventional filters have served the industry well and they will continue to do so well into the future. However, the need to meet improved performance and warranty expectations will force engineers, components suppliers, manufacturers and end users to address historical problems by deploying new filtration technologies.

Engineers must continue to incorporate new technology into their systems, to improve performance, reliability & availability, while reducing warranty costs. The average working pressure of mobile hydraulic equipment will increase from a maximum of 350 bars to 450 bars over the next 3-5 years. The hydraulic and transmission fluid power systems of mobile equipment today are under tremendous strain and performance expectations, and reliability will need to increase. Furthermore, the hydraulic industry as a whole is under 'attack' from electro-mechanical equipment solutions.

This additional strain over industrial power units experienced by mobile hydraulics is due to the following conditions:

1) The environment in which it is generally used.
While there's plenty of 'industrial' hydraulic equipment working in dirty conditions and extreme temperatures. This is typical rather than the exception for 'mobile' systems.

2) Decreasing hydraulic tank (reservoir) size.
Due to space and weight constraints, the reservoir capacity of 'mobile' hydraulic equipment is always less than ideal. This means that there's less oil circulating in the system, thus contaminants in mobile fluids reach far greater concentrations.

3) Increased working pressure.
Again, while there are plenty of high-pressure industrial hydraulic systems around, it is mobile equipment that always pushes the envelope in this area. In a hydraulic system, power is proportional to pressure and fluid flow. Also, force is related to area and pressure. If working pressure is increased, then flow and area can be decreased, thus providing the same power and force from smaller components. On mobile equipment where space and weight are at a premium the advantages are quite obvious.

4) Contamination control.
This will be more important than ever because the more heavily loaded the components of the machine, the more susceptible the machine is to wear and damage from

particulate contamination. Size is already important, but in this new environment it will become absolutely critical to eliminate the largest threat.

These conditions will greatly impact reliability of our hydraulic systems. When operating pressures increase, so do loads on a lubricated components surface. It will be critical to maintain clean lubrication between heavily loaded components on mobile equipment. When operating at 350 or even 450 bars, cleanliness of the oil will be critical for optimum performance, reliability and maintenance costs.

The good news is help is here in the form of new magnetic core technology. So, regardless if you are OEM or end user, now is the time to act and stay ahead of the curve.

CONTACT

The author has a broad engineering background and trained in the UK. He has owned and run a many successful companies covering a variety of industries. His involvement with the racing industry brought about the innovation and development of the unique MAGNOM Technology now being adopted by the hydraulic and lubrication industries.

Jobey Marlowe, VP Technology

Magnom Corporation,
Innovation Centre
Warwick Technology Park
Gallows Hill
Warwick UK
CV34 6UW

Web: www.magnom.com

E-mail: jobey.marlowe@magnom.com