# An Instrument for Assessing Metallic Wear Debris Captured by Filter Patch or Magnetic Chip Detector

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**Abstract**

A prototype instrument has been developed that enables the quantification of significant metallic wear debris captured on either a filter patch (also known as a porous membrane) or a magnetic chip detector. With the introduction of fine filtration to machinery lubrication systems, the effectiveness of traditional oil analysis methods such as Spectrometric Oil Analysis (SOA) is significantly reduced, often to the point where it ceases to provide useful information about machinery health. The filter element in a lubrication system is a rich source of machinery health information however it is not often considered or exploited for condition monitoring. Whilst the filter patch technique is a convenient way for extracting the debris from a filter element, analysis of the captured debris has traditionally been tedious, time consuming and can lack repeatability. Other methods do exist to quantify filter debris, however they typically involve the transportation of the entire filter element to a laboratory, which is not always practical. The instrument that has been developed enables the metallic content of a filter patch to be quantified for trending or to identify which filter patches require further detailed examination. The instrument has also been designed to liberate and quantify ferromagnetic debris captured on a magnetic chip detector. Magnetic chip detectors are used widely in aviation machinery, however the assessment of captured debris is generally limited to a periodic visual inspection. The instrument uses a unique method to liberate and recover the debris combined with a commercially available inductive wear debris sensor.

**Keywords:** Wear Debris Analysis, Filter Patch, Magnetic Chip Detector, Machinery Health.

## Introduction

The extraction and analysis of metallic wear debris from a lubrication system can be highly effective for identification of incipient failures of oil-wetted components [1,2,3,4]. Traditional wear debris analysis methods such as Spectrometric Oil Analysis (SOA) suffer from particle size limitations (i.e. typically they detect particles less than 8 microns [4]) and fine filtration (e.g. a Beta efficiency of 200 or greater for 5 micron particles) present in modern machinery further reduces the effectiveness of this technique. In typical oil-wetted aircraft machinery, the two practical options remaining for obtaining wear debris for analysis are the filter and the magnetic chip detector. The filter is a rich source of information about wear-related failure modes that in the past has rarely been exploited in the field. The extraction of debris from filter elements has typically been cumbersome and timely analysis of the debris has been difficult to reliably achieve by non-experts. Magnetic chip detectors are devices that provide an indication (to operators or maintenance staff) when sufficient ferromagnetic debris is accumulated on the sensor to complete the electrical circuit between two magnets separated by an insulator. Analysis of debris captured by either a filter or a magnetic chip detector can provide information regarding the health of oil-wetted dynamic components, however the assessment of captured debris has traditionally been difficult, tedious and subject to some interpretation. It should be noted that a simplified version of a magnetic chip detector (known as a magnetic chip collector) consists of a simple magnet inserted in the scavenge oil line. Magnetic chip collectors do not provide any indication of the collected debris and rely solely on periodic visual inspection. Either magnetic chip detectors or magnetic chip collectors could be processed in the instrument described below.

## Description of Instrument

The instrument was designed to reduce the burden and increase the repeatability associated with analysis of both filter patches and magnetic chip detectors, particularly where the machinery is operating in a remote location. The instrument consists of an Entry Stage, a commercial inductive wear debris sensor and a Recovery Stage all mounted on a common retort stand (Figures 1 and 2). For both filter patch analysis and magnetic chip detector analysis compressed air is used to liberate the debris and transport it through the instrument to the Recovery Stage where it can be retrieved.


*Fig. 1: One of the prototype instruments (filter patch variant shown)*

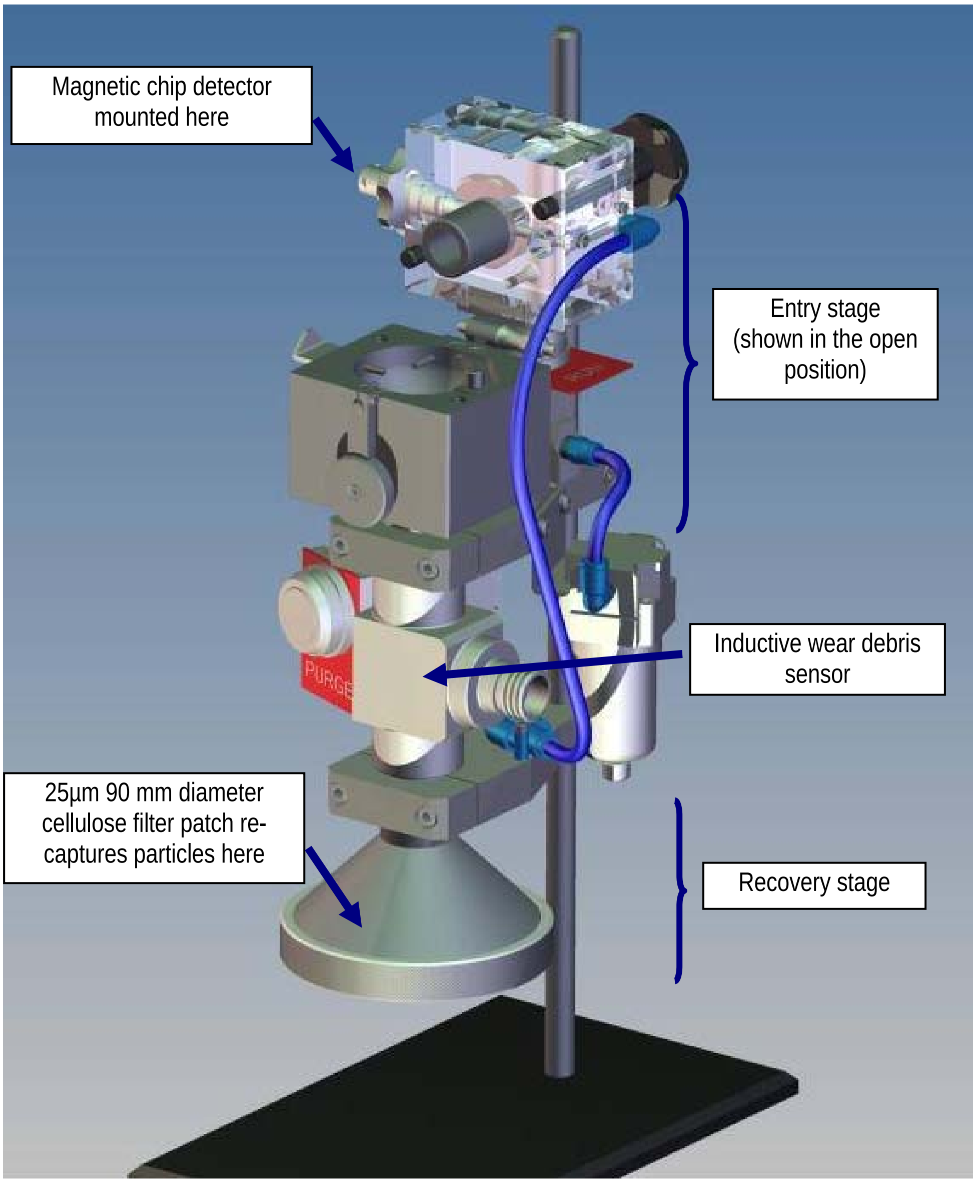


*Fig. 2: Cross-section of instrument showing the key components (magnetic chip detector variant shown)*

Two Entry Stages have been designed for use with the instrument. The first consists of an assembly that accommodates a filter patch whilst the second accepts a common type of magnetic chip detector. The operation of both variants will be described in detail below. Either Entry Stage can be fitted to the instrument using a quick-release hinge mechanism. The upper lid of each Entry Stage consists of a series of passages that convey compressed air to outlets or jets directed at either a filter patch or the magnetic portion of the magnetic chip detector (Figure 3). The Entry Stage lids are transparent to allow observation of the process. Access to the Entry Stage is via two securing screws that ensure positive sealing of the lid to the body. The Entry Stage chamber is designed to have a smooth transition to the inductive sensor bore with no cavities or ledges to inadvertently trap debris.

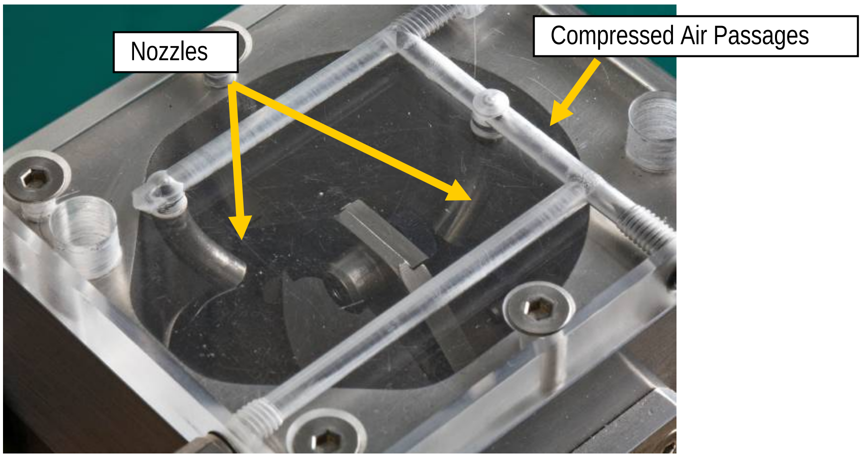


*Fig. 3: Entry Stage lid (filter patch variant shown)*

After leaving the convergent Entry Stage the debris is transported through a commercial inductive wear debris sensor where the metallic particulate is detected. There are several commercial suppliers of inductive wear debris sensors and the instrument can operate with any inductive sensor with only minor changes needed to the Entry and Recovery Stage connections. The sensor used for the prototype instrument was a 3/8” bore MetalSCAN™ sensor manufactured by GasTOPS Ltd. Whilst this sensor is normally employed in scavenge oil lines, the sensor performance is not adversely affected when using air as the transport medium, in fact correct sensor operation is typically confirmed by passing metallic spheres of known size through a dry sensor [5]. Commercial inductive wear debris sensors are generally supplied with dedicated software for displaying the output of the sensor and in this case the standard software for this sensor was used. The software displays size and count information for ferrous and non-ferrous debris; it can also provide an approximate mass of ferrous debris that is inferred from the particle size information, however this was not recorded or used during the testing of this instrument. According to the sensor manufacturer the smallest detectable particle for the 3/8” sensor is 70µm (ideal) [6] however testing at this level with real particles presents some significant particle handling challenges and has yet to be completed.

The debris that has passed through the sensor then enters the diverging Recovery Stage (Figure 4) where it is trapped by a 90 mm diameter Whatman® number 4 filter paper (20-25 µm retention). Embedded in the centre of the recovery filter paper support grill is a strong magnet that attracts the ferromagnetic debris (Figure 5). Ferromagnetic debris is attracted to the area of the patch under the influence of the magnet whilst the remainder of the debris tends to migrate to the outer perimeter. The magnet allows the non-ferromagentic debris (typically less important) to be disgarded or transferred to a receptacle, whist the ferromagnetic debris is retained for further analysis if necessary. Once the recovery filter paper is removed from the support, the influence of the magnet is removed and the debris can be transferred to another receptacle for further composition or morphological analysis if required. The larger diameter filter paper used to trap the recovered debris also serves as a clear visual indicator that the filter patch has been processed.

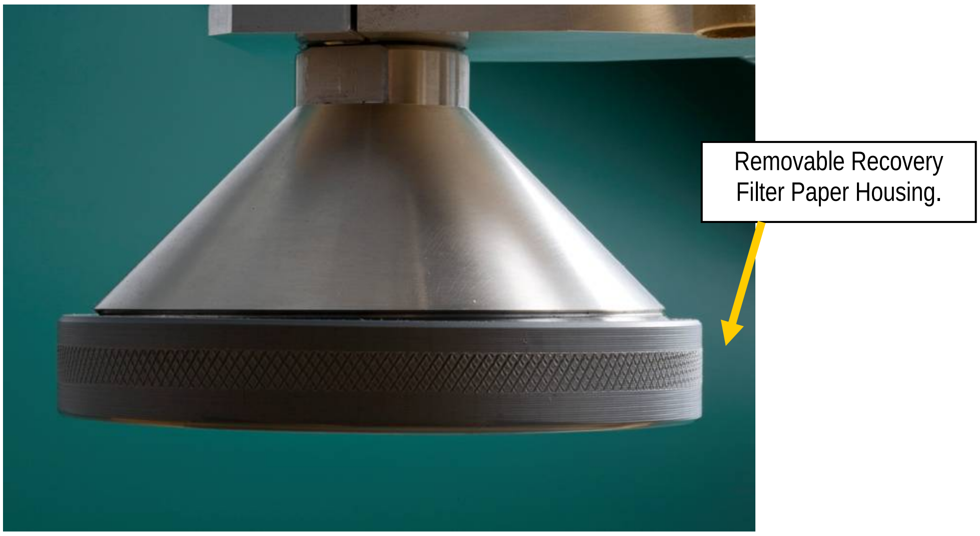


*Fig.4: Recovery Stage showing divergant shape and removable recovery filter paper housing*

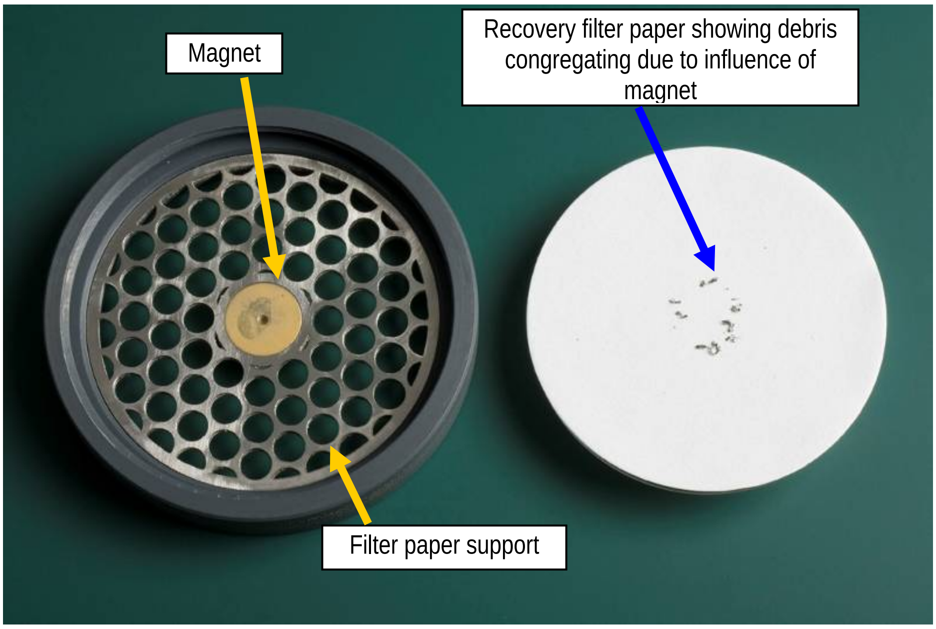


*Fig. 5: Recovery Stage filter paper support grill (left) showing embedded magnet and recovery filter paper with debris (right)*

## Filter Patch Analysis

The filter patch method can be used to capture wear debris extracted from various sources including oil filters and sump oil using low cost equipment. Where the filter patch technique is used to assess the health of a fleet of machines, manual analysis of the captured debris is difficult due to the tedious nature of the work and the time required. The manual version of this technique involves extraction of the filter debris into a slurry which is then passed through a filter patch to capture the desired level of particulate (Figure 6). The slurry is obtained by sealing the exit ports of the filter element and then placing the element in a container approximately half full of a suitable solvent. The cylindrical bottle is not filled to capacity as this would substantially reduce the agitating effect (sloshing) of the solvent and hence impact the extraction efficiency. The container is then agitated to liberate the debris. The slurry is then passed through a 47 mm diameter, 60 µm nylon filter patch inserted into a patch-making funnel to capture the debris. Once the filter patch has dried it can be inserted into the Entry Stage and processed.


*Fig.6: Manual filter debris extraction process using filter patch method*

The filter patch Entry Stage consists of a clamp that secures the filter patch along part of one side, combined with a support arrangement that allows it to be rotated 90 degrees to a vertical orientation during processing. The creation of a filter patch typically leaves a 5 mm wide area free of debris around the perimeter of the filter patch and it is here that the filter patch is clamped, thus avoiding entrapment of debris in the clamp. Once the filter patch has been clamped, the Entry Stage cap is secured. The counter-balanced handle on the side of the Entry Stage is then rotated 90 degrees which rotates the filter patch and allows it to hang vertically with the clamp uppermost (Figures 7 and 8). At this stage any loose debris that falls through the inductive sensor would still be detected and added to the total count, however the design of the filter patch support tends to keep the filter patch partially folded with debris in place until compressed air is applied. Low pressure compressed air (typically less than 35 kPa) is then applied to excite the filter patch into a fluttering motion thus dislodging and accelerating the debris.

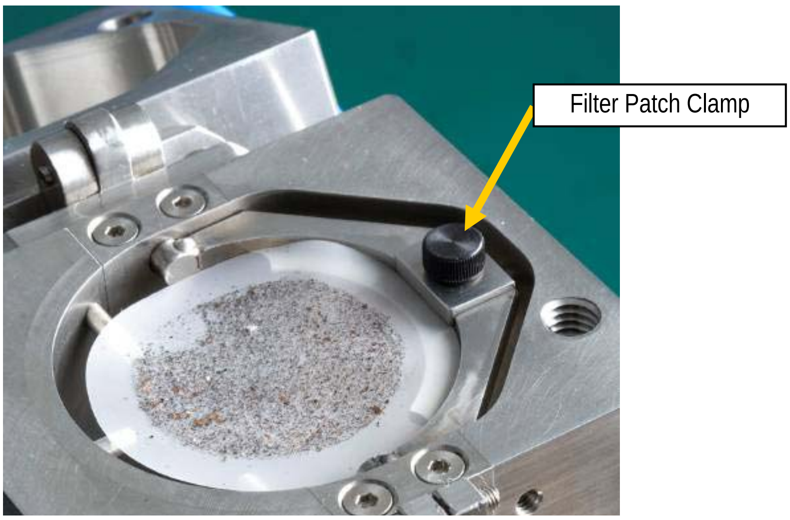


*Fig. 7: Entry Stage showing filter patch clamped in installation position*

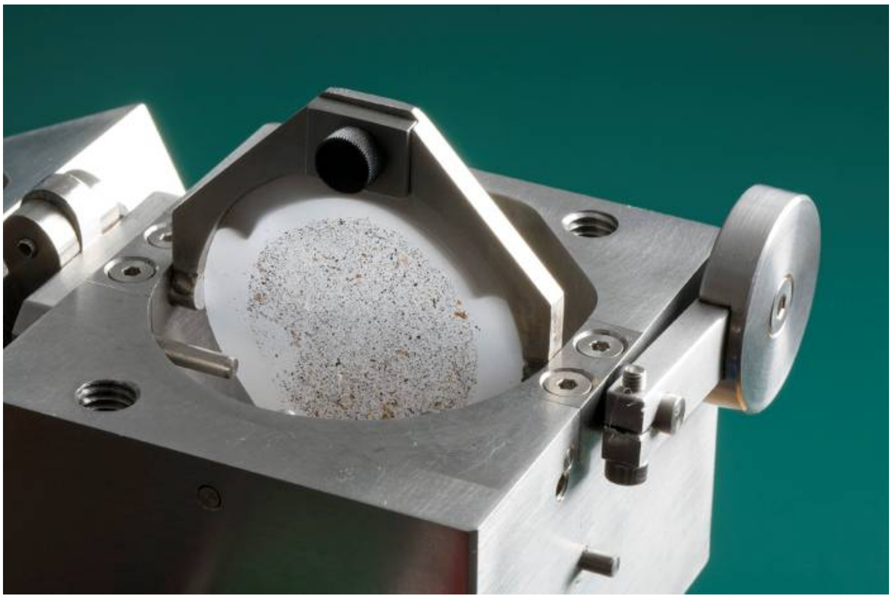

*Fig.8: Entry Stage showing filter patch in the rotated position*

**Results for Filter Patch Testing**

Two prototype instruments have been built and tested in the laboratory. For testing purposes, filter patches were concocted using real wear debris (mix of rolling contact fatigue and adhesive wear particles) recovered from real machinery (Figure 9). All of the debris used was SAE 52100 bearing steel in the size range 500 to 1200 µm. This size range is consistent with typical limit guidance provided by aircraft manufacturers.

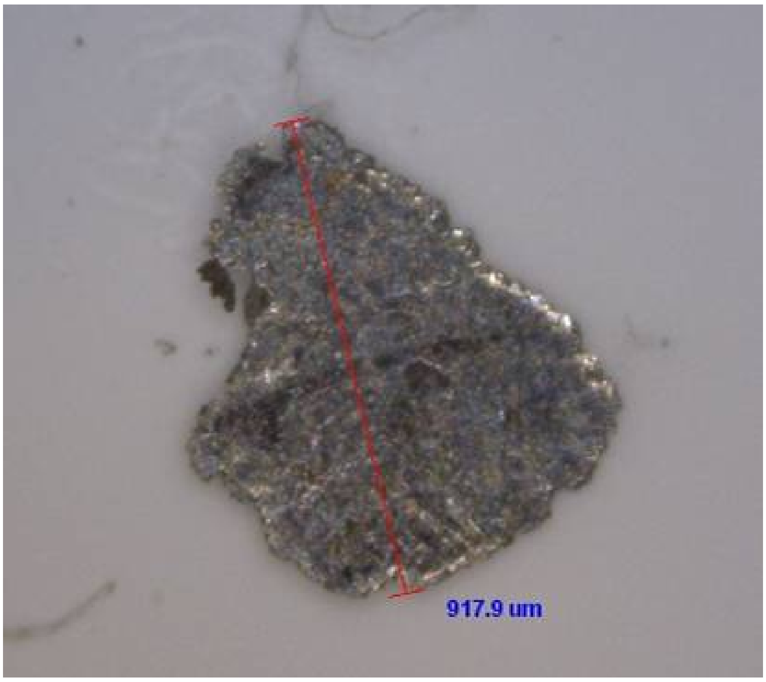


*Fig.9: Example of wear debris used for testing the instrument*

Table 1 contains a sample of results obtained during testing of the filter patch version of the instrument. Several of the tests resulted in more particles being reported than were present on the filter patch. Whilst the exact reason for this is unknown, the discrepancy could result from either particles breaking up during transit through the instrument, un-recovered particles hiding in the instrument from previous tests or residual build debris.  A cleaning technique has been developed to address the latter two possible causes.  Initial testing of the instrument [7] showed a significant discrepancy between the actual number of particles and those recorded by the instrument, however this was subsequently corrected by optimizing the sensor detection thresholds and using a smaller bore sensor that increased the minimum detectable particle resolution.

*Table 1: Sample of test results from filter patch testing*

| Test | Ferromagnetic Particles on Filter Patch | Ferromagnetic Particles Counted by Sensor Software | Ferromagnetic Particles Retrieved from Recovery Filter Patch |
|---|---|---|---|
| 1 | 6 | 6 | 6 |
| 2 | 6 | 8 | 6 |
| 3 | 6 | 6 | 6 |
| 4 | 6 | 7 | 6 |
| 5 | 6 | 8 | 6 |
| 6 | 6 | 6 | 6 |
| 7 | 6 | 5 | 6 |
| 8 | 6 | 7 | 5 |
| 9 | 6 | 5 | 6 |
| 10 | 6 | 7 | 6 |
| 11 | 6 | 6 | 6 |
| 12 | 6 | 6 | 6 |
| 13 | 6 | 6 | 6 |
| 14 | 6 | 6 | 6 |
| 15 | 6 | 4 | 6 |
| 16 | 6 | 6 | 6 |
| 17 | 6 | 6 | 6 |
| 18 | 6 | 6 | 5 |
| 19 | 6 | 7 | 6 |
| 20 | 6 | 6 | 6 |

## Magnetic Chip Detector Analysis

An Entry Stage was also designed to enable the removal and assessment of ferromagnetic debris captured by a magnetic chip detector (see Figures 10 and 11). Magnetic chip detectors are used widely in aviation machinery, however the assessment of the captured debris is predominantly achieved by rudimentary periodic visual inspection and comparison with size limits provided by the manufacturer.

*Fig.10: Common magnetic chip detector with debris*

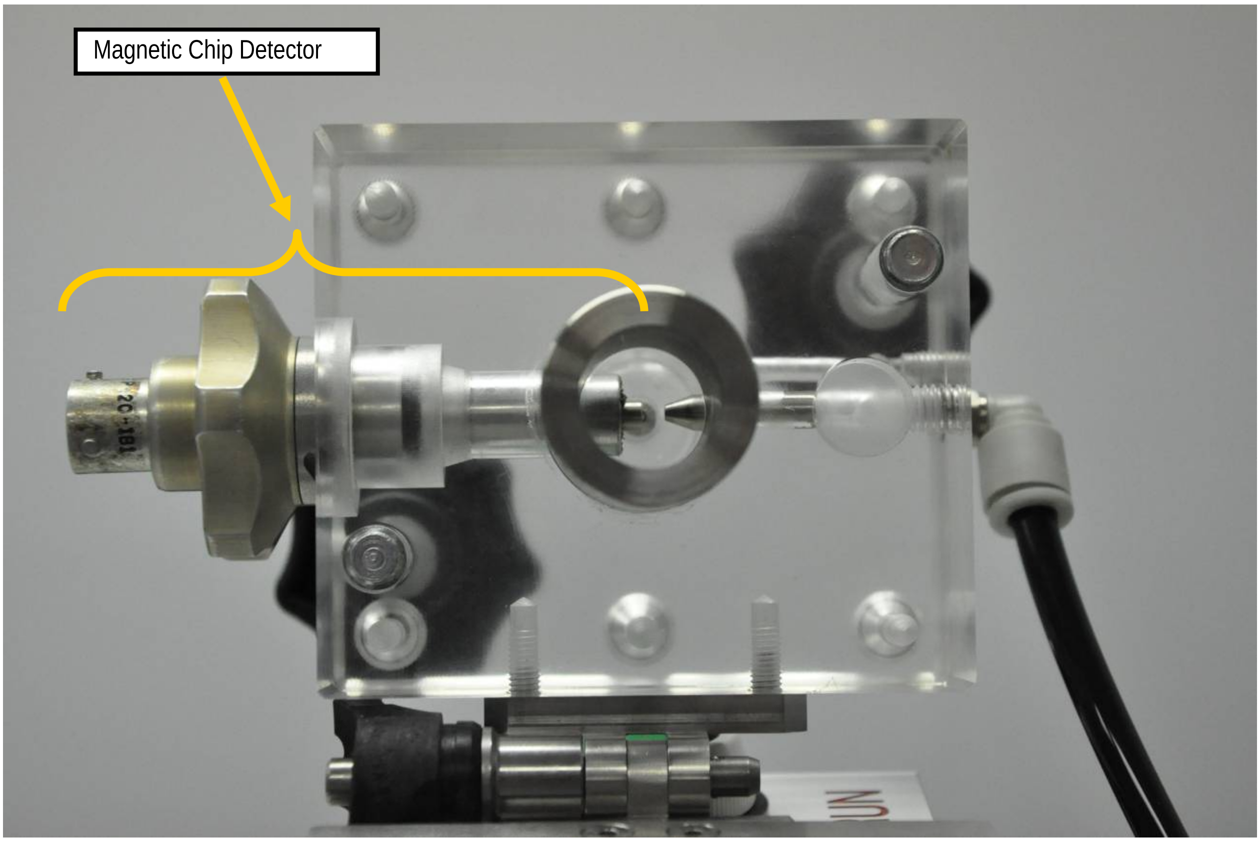


*Fig.11: Magnetic chip detector installed in Entry Stage*

In this version of the Entry Stage, vertical and horizontal nozzles are arranged so that high velocity compressed air impinges on the captured debris thus liberating it from the magnetic portion of the chip collector. Simultaneously, a curtain of downward flowing air is provided by a circumferential outlet (Figure 12) to ensure all debris is directed towards the inductive sensor. For the particular style of magnetic chip detector used in the prototype (Tedeco B8734, Figure 10), the horizontal nozzle is offset from the centreline of the magnetic region to ensure it impinges on the area where debris is collected. The magnetic chip detector is then rotated manually to ensure that all ferromagnetic debris is removed.

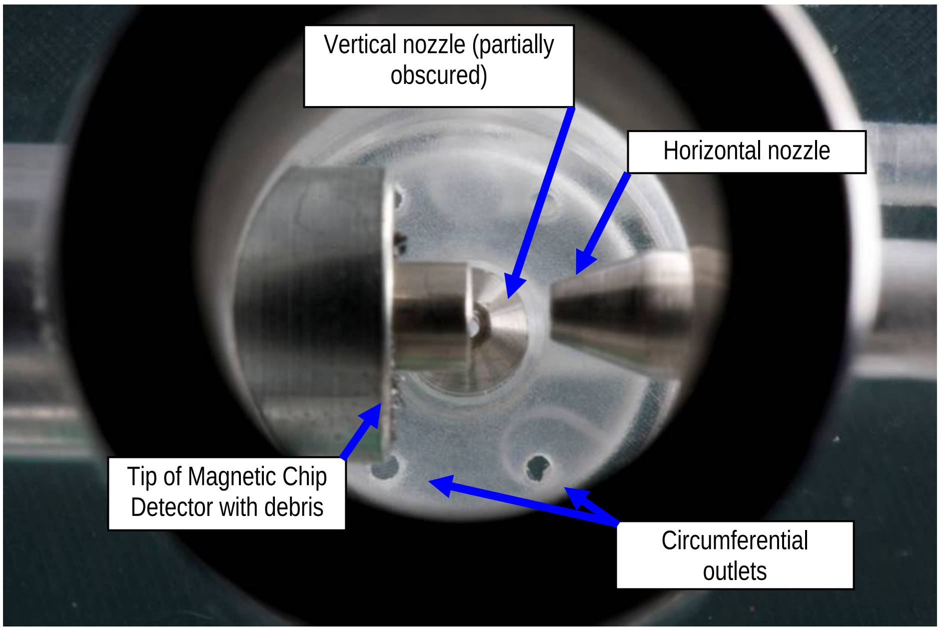


*Fig.12: Enlarged view of modified Entry Stage showing nozzles and circumferential outlets (partially obscured)*

<u>Results for Magnetic Chip Detector Testing</u>

Initial testing of the magnetic chip detector Entry Stage indicated that the method was effective at removing and transporting the debris through the apparatus (Figures 13 and 14).

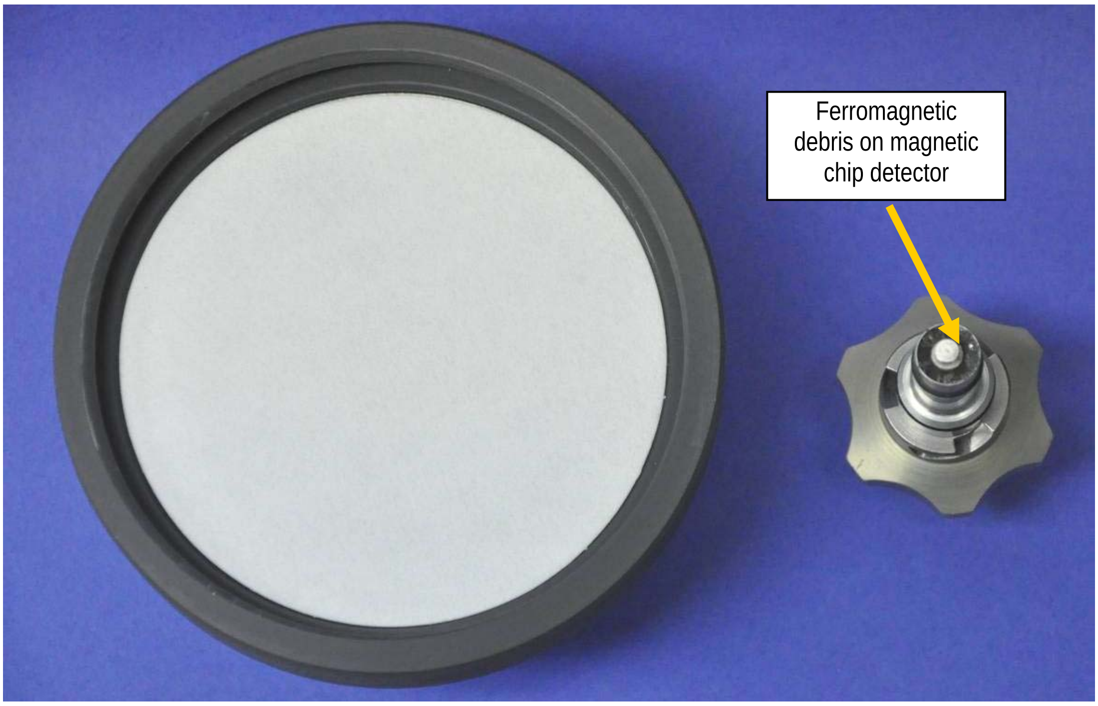


*Fig.13: Recovery filter paper and magnetic chip detector prior to processing*

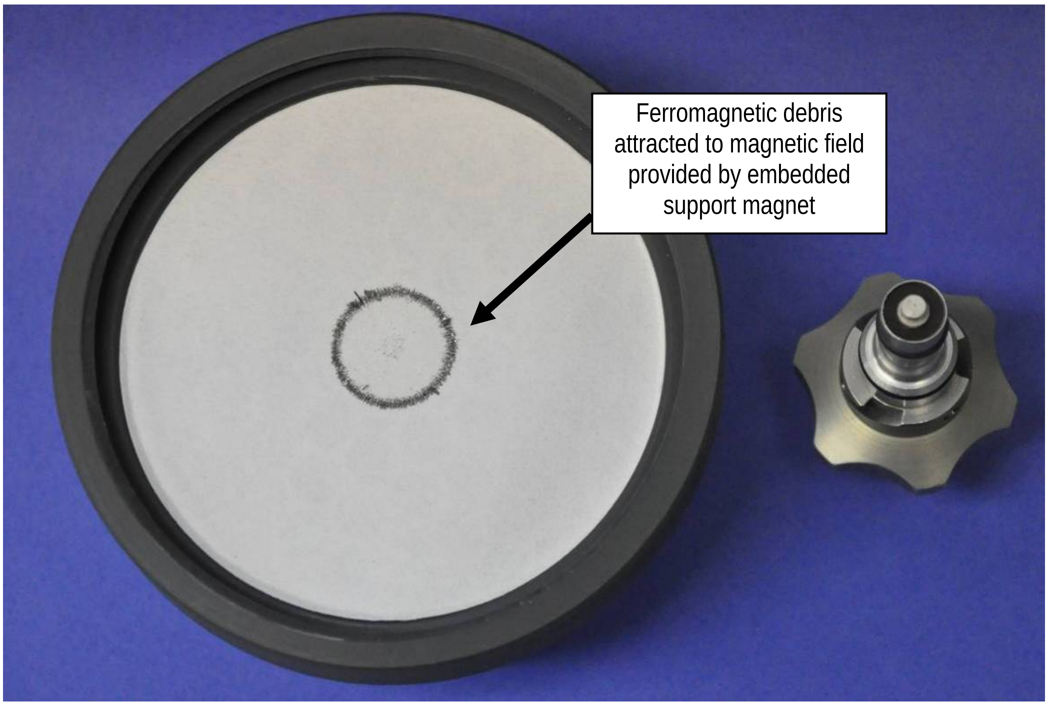


*Fig.14: Recovery filter paper and magnetic chip detector after processing in instrument*

Typically debris greater than 500 micron is considered significant when assessing debris captured by a magnetic chip detector; all debris used for this testing was SAE 52100 bearing steel within the size range 500 to 1200 µm. The debris used for this testing was a mix of rolling contact fatigue and adhesive wear flakes generated in a dedicated bearing failure test rig. Whilst the results (Table 2) indicate not all particles were detected, multi-particle traces (Figure 15) were regularly observed, which may indicate the velocity of the particles were beyond the stated limits for the software. The example in Figure 15 shows three particles passing through the sensor in approximately 25 msec; it is possible that for this unusual application of the sensor, some enhanced processing of the particle detection signal is required.

*Table 2: Sample of test results from magnetic chip detector testing*

| Test | Ferromagnetic Particles on magnetic chip detector | Ferromagnetic Particles Counted by Sensor Software | Ferromagnetic Particles Retrieved |
|---|---|---|---|
| 1 | 8 | 3 | 7 |
| 2 | 8 | 3 | 8 |
| 3 | 8 | 5 | 8 |
| 4 | 8 | 2 | 8 |
| 5 | 8 | 3 | 8 |
| 6 | 8 | 4 | 8 |
| 7 | 8 | 2 | 8 |
| 8 | 8 | 5 | 8 |

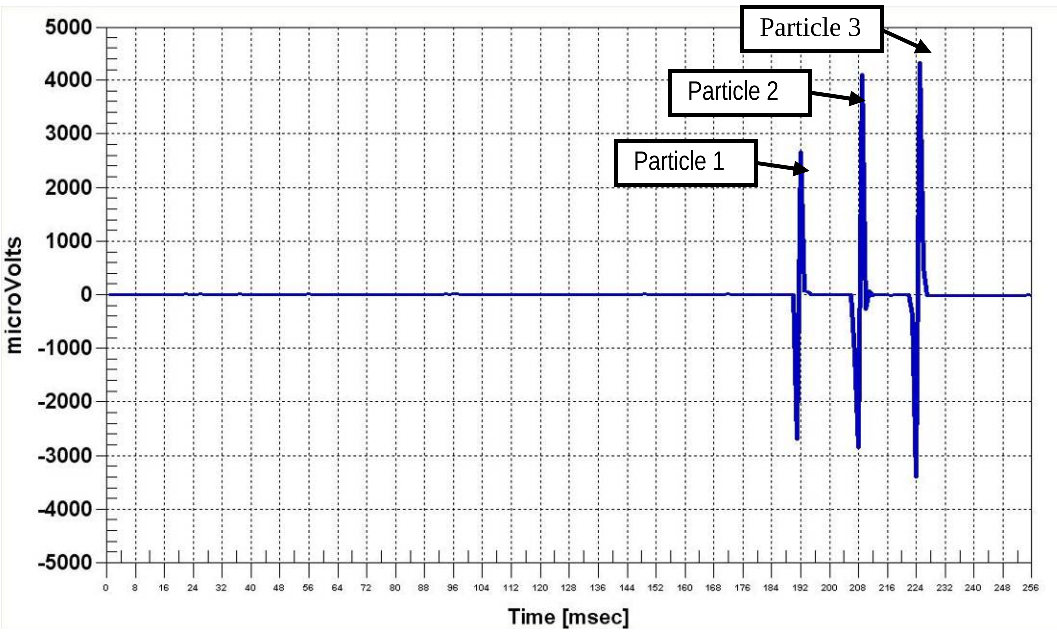


*Fig.15: Time trace from MetalSCAN™ software showing multiple particles within approximately 25 msec*

## Conclusion

An instrument has been described that shows some potential for the rapid quantification or screening of wear debris captured on filter patches or magnetic chip detectors. The prime focus of the instrument was to reduce the analysis time associated with filter patches and enable repeatable quantification of debris captured on magnetic chip detectors. The principal components and operation of the instrument have been described. Test data from both variants have also been presented. This device has been submitted for patent protection examination at the time of writing.

## Acknowledgements

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