CT Associates, Inc.
Creative Technology
P.O.BOX 441, EXCELSIOR, MINNESOTA 55331-0441
Telephone: (612)470-2131 Telefax: (612)470-2132

# An Evaluation of Particle Shedding from the White Knight Pump
**Model Number AP100EXT2**

Submitted to:

John Simmons
White Knight Fluid Handling, Inc
1077 Watson
Hemlock, MI 48626

Submitted by:

Dennis D. Chilcote
CT Associates, Inc.
10777 Hampshire Avenue South
Bloomington, MN 55438

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## INTRODUCTION

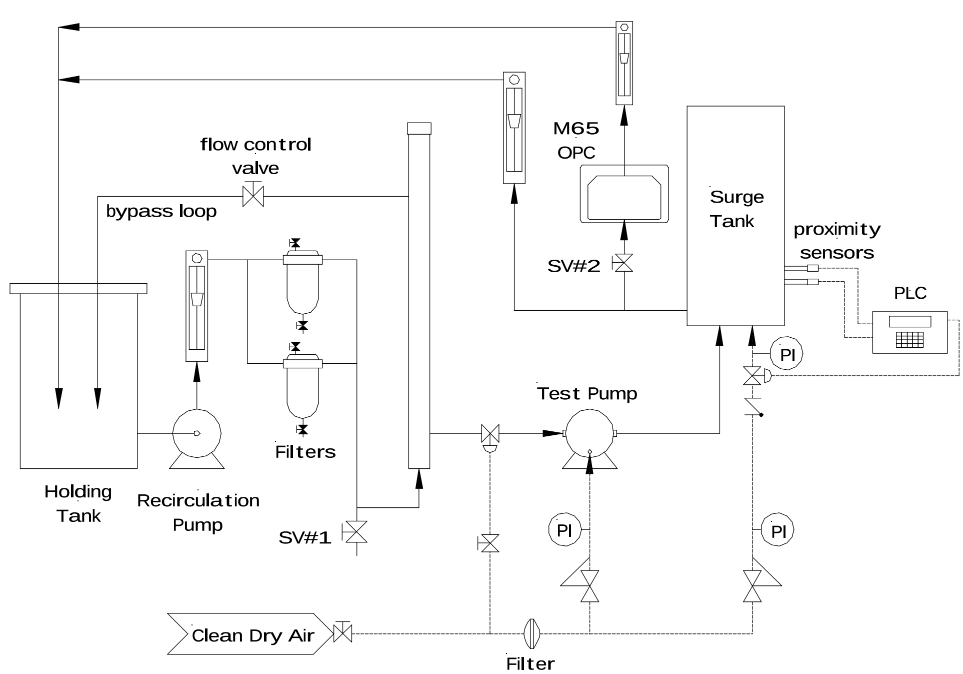
Two White Knight Model AP100EXT2 pumps were obtained for evaluation of particle-shedding characteristics and trace metal extraction performance. Particle shedding was measured in ultrapure water using a test stand specifically assembled for this evaluation. The stand was designed to provide a constant supply of filtered water to the pump while minimizing pulsation both upstream and downstream of the pump. The White Knight pump designated for trace metal extraction testing was used to determine the appropriate connection and startup sequence for this test. The initial flush up of the test pump at 13.2 liters/min was conducted while the air supply to the pump was shut off to determine the passive particle shedding curve. The pump was first operated at 13.2 liters/min to determine the initial active particle flush up curve. The pump was then operated at 16.3 liters/min to establish the long-term particle flush up curve. Finally, the air supply pressure was set at 40 psig and the pump was operated at several different flow rates. Particle concentrations downstream of the pump were recorded at each flow rate to establish the relationship between steady-state particle shedding from the operating pump as a function of flow rate.

## TEST PROCEDURE

The test system is shown schematically in Figure 1. This system was located in a Class 100 cleanroom. The main components of the test unit included:

- a 50-liter holding tank
- a centrifugal pump to circulate water through the main loop
- dual Durapore Z filters to filter the influent to the test pump
- an influent holding tank for the test pump
- the test pump
- a surge control tank downstream of the test pump with associated level controls to ensure uniform flow to the optical particle counter
- a Particle Measuring Systems M50 optical particle counter (4 size channels, ≥ 0.05, ≥ 0.10, ≥ 0.15, and ≥ 0.20 µm)

Figure 1. Pump Test Stand



The recirculating pump delivered 36 liters/min through the main loop. The White Knight test pump withdrew approximately 13-31 liters/min from the main loop, depending on test conditions, and delivered this flow to the surge tank. The surge tank, which served as a large pulse dampener for flow to the particle counter, was pressurized with filtered air, and discharged water at a very uniform rate back to the holding tank. The particle counter monitored the concentration of particles in the effluent from the surge tank. Since this tank was closed and pressurized, air in the tank would dissolve in the water and the level would slowly rise over time. Thus the test system was designed to allow proximity switches to control the level in this tank. When the high-level switch closed, a solenoid valve in the airline to the tank would open, which would bleed pressurized air into the tank and lower the level. When the low-level switch opened, the solenoid valve would close. This operating scheme maintained the liquid in the tank between the two level switches, which were set as close together as practical.

A Cole-Parmer programmable logic controller monitored both level switches. This controller activated a relay when the high-level switch closed, and inactivated the relay when the low-level switch opened. The relay controlled the status of a solenoid valve in the airline to the surge tank. A regulator on the air supply line was set at a pressure just slightly above the steady-state pressure in the tank. Flow to the particle counter was fixed at 100 ml/min.

The system was initially started up with a short length of tubing (spool piece) in place of the test pump. The particle counter was connected to sample port SV#2, the valve isolating the test loop was opened and the flow control valve in the bypass loop was partially closed. The system was operated under constant flow conditions at 13.2 liters/min until a steady particle count was observed downstream of the surge tank. At this point the test system was qualified to begin testing.

The setup of the test system was conducted with the White Knight pump received for trace metal extraction. After connecting this pump into the test stand, it was flushed passively and then operated briefly to ensure that the existing test protocol was appropriate for this pump. This evaluation did show that, at the beginning of the passive flush test, the pump must be cycled a few times to clear air trapped in the pump. Following the initial shakedown of the test system, the second pump (SN P1#EXT00102) was installed in the system and used to provide the actual test data.

For the test program, the isolation valve was opened, the pump was cycled a few times to clear entrained air, and a passive flush of the as-received pump was conducted at 13.2 liters/min for approximately 24 hours. During this time the air supply line to the pump was closed. Following the initial flush up test, the pump was operated at an inlet air pressure of 15 psig and a flow rate of 13.2 liters/min for another 24 hours. When particle shedding had reached a point where the rate of change of particle shedding with respect to time was low, the flow rate was increased to 16.3 liters/min and operated for approximately 10 days to determine the long-term particle shedding characteristics of the pump. The air inlet pressure was adjusted to 40 psig, and particle shedding as a function of flowrate was measured over the flowrate range of 13 to 31 liters/min.

## PARTICLE SHEDDING ANALYSIS

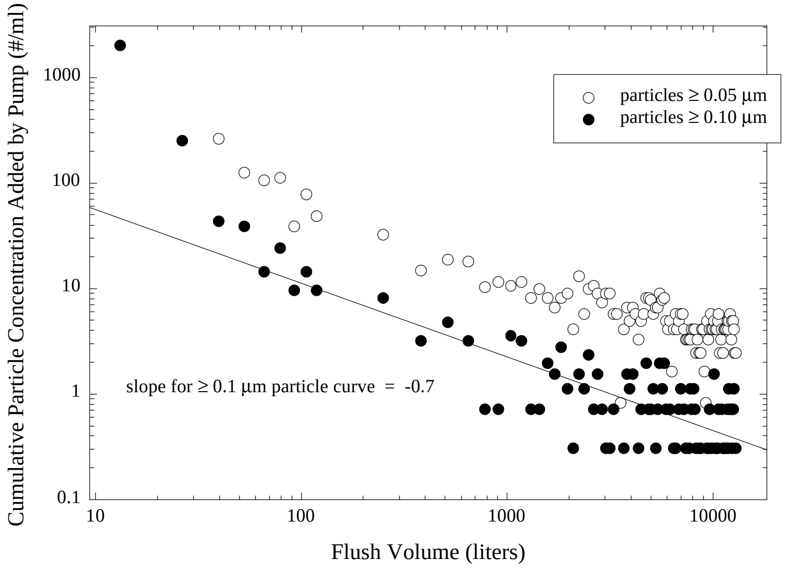
Initially, the pump was bypassed to determine the particle background level of the system. Background particle levels are shown in Table 1.

**Table 1. Background Particle Concentrations**

| | Cumulated Particle Concentration (#/ml) | | | |
|---|---|---|---|---|
| | ≥0.050 | ≥0.10 | ≥0.15 | ≥0.20 |
| test loop without pump | 2.0 | 0.10 | 0.05 | 0.05 |

The White Knight pump was then placed in the loop and the valve on the bypass loop was partially closed, forcing water through the test pump. The pump was flushed at 13.2 liters/min to establish the passive flush up curve. The passive pump shedding curves for particles ≥ 0.05 μm and ≥ 0.10 μm are shown in Figure 2.

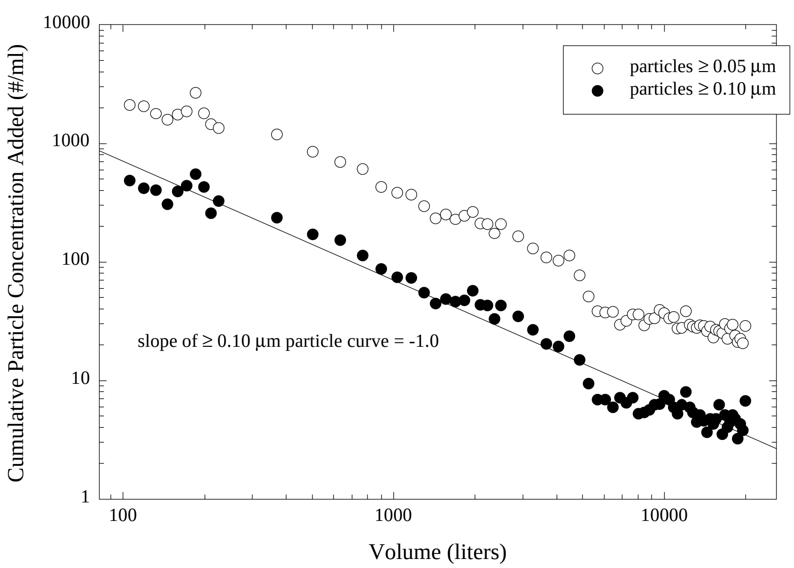
**Figure 2. Passive Flush Up Curve, White Knight AP100EXT2 Pump**




This pump was shedding less than 1 particle/ml ≥ 0.10 µm after 3,200 liters of flushing.

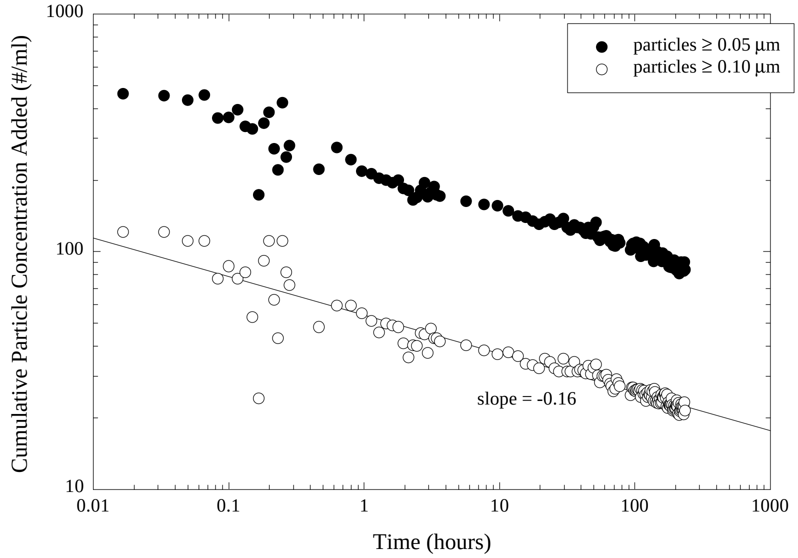
Following this test, the air supply line to the pump was opened and the pump was operated at 13.2 liters/minwith an air inlet pressure of 20 psig. The initial active pump shedding curves for particles ≥ 0.05 µm and ≥ 0.10 µm are shown in Figure 3.

**Figure 3. Initial Flush Up Curve at 13.2 liters/min**



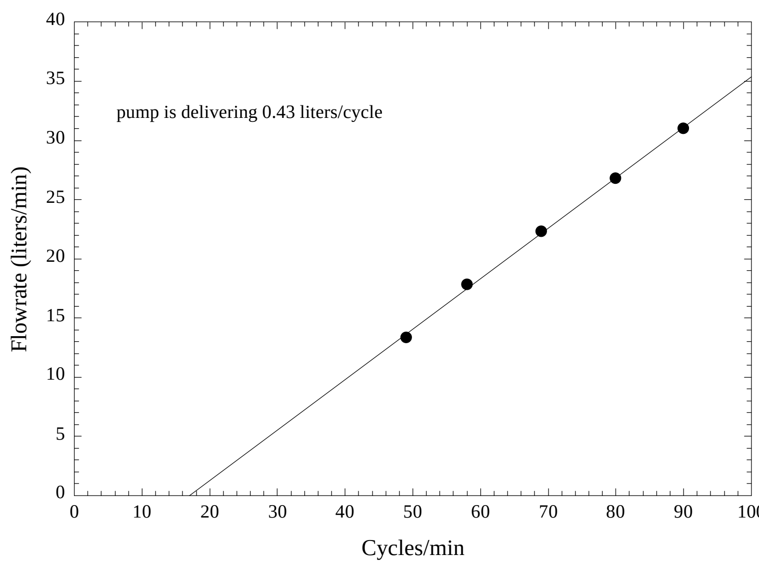

Following the initial flushup, a long-term flushup of the pump was undertaken to evaluate particle cleanup over time. The flowrate was increased to 16.3 liters/min and operated for approximately 10 days. Results ar presented in Figure 4. Note that the pump continued to clean up over this extended interval. In addition, the slope of the cleanup curve is significantly more shallow than that of the initial flushup shown in Figure 3. Note that since these two graphs are plotted in log-log space, the slope would be the same regardless of whether volume or time is used for the absicssa.

**Figure 4. Long-Term Particle Shedding at 16.3 liters/min**



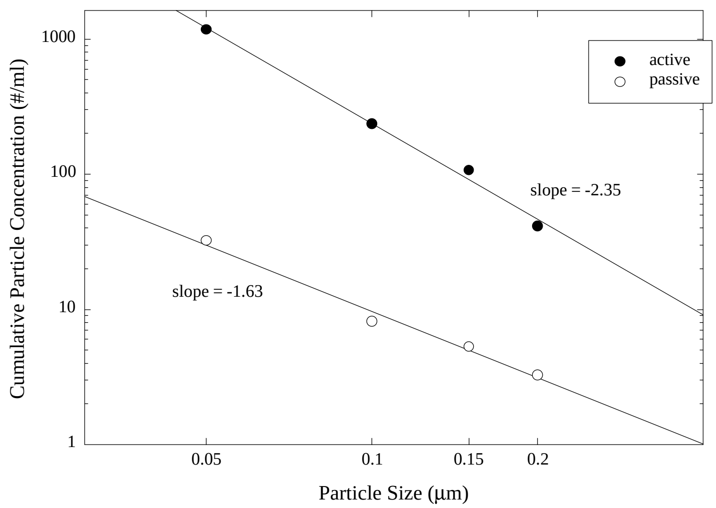

For the remaining testwork in this report, the pump was operated at an inlet air pressure of 40 psig, and the flowrate was controlled by adjusting the valve on the downstream flowmeter which modulated the backpresssure on the pump. The pump was tested up to about 31 liters/min, which is the practical capacity of the test system. The relationship between cycle rate (cycle defined as two strokes of the shaft) and flow rate of the AP100EXT2 pump (when the pump was operated at 40 psig) is presented in Figure 5

**Figure 5. Relationship between Flow Rate and Cycle Rate**
Inlet air pressure = 40 psig



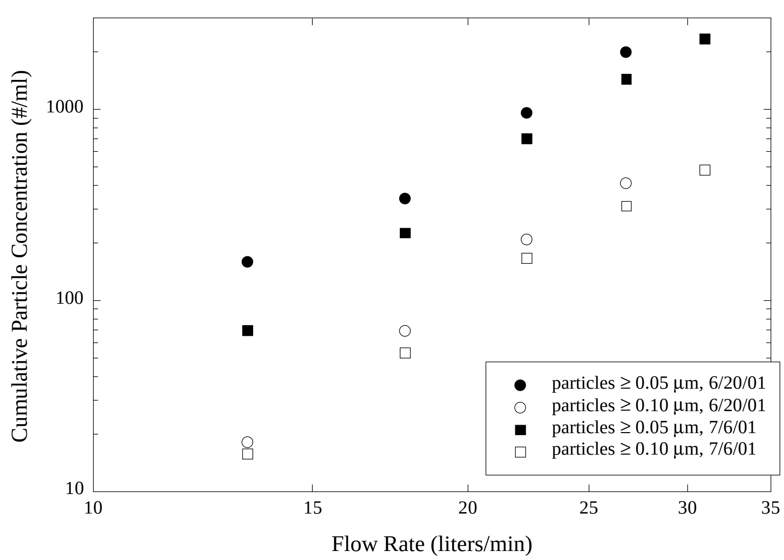
The particle size distributions for particles shed from the pumps under passive and active conditions are shown in Figure 6. The distributions show no abnormal characteristics. The active curve is somewhat steeper than the passive curve, with the curve developed under operation being slightly more characteristic of natural particle populations.

**Figure 6. Size Distribution of Shed Particles ≥ 0.05 µm**



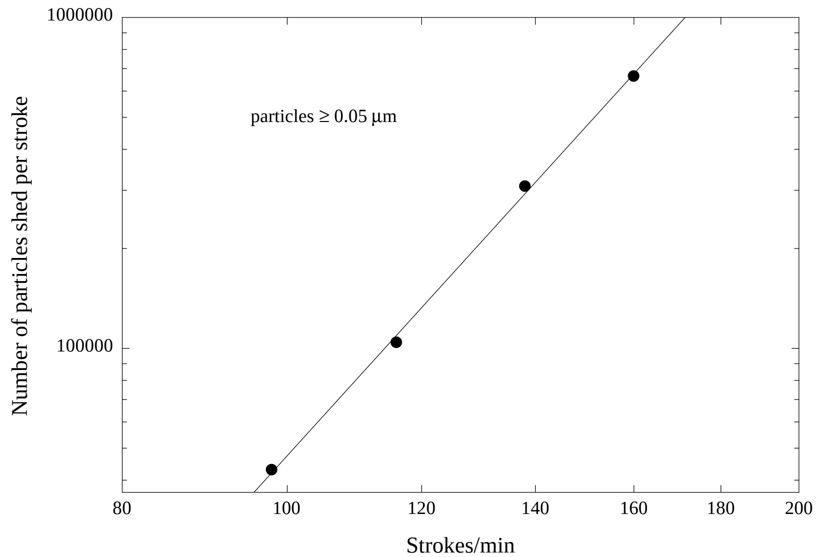

Results for particle shedding as a function of pump cycle rate soon after the start of testing and at the very end of the test program are shown in Figure 7. All data were taken with an air supply pressure to the pump of 40 psig, except for the data at 31 liters/min, which required an inlet supply pressure of 50 psig. At each flow rate, the pump was operated until particle shedding had stabilized (typically several hours) before changing to the next flow rate. The results presented in Figure 7 show how the curve shifted downward over time, although the slope remained relatively constant. The data follow a straight line when plotted in log-log space, which appears typical for this type of pump.

**Figure 7. Effect of Flow Rate on Particle Shedding**
inlet air pressure = 40 psig



Results presented in Figure 8 show that the number of particles shed per stroke increases as the stroke rate increases. This is very typical for pneumatic pumps.

**Figure 8. Effect of Stroke Rate on the Number of Particles Shed per Stroke**




Quasi-steady-state particle shedding data for all particle sizes are presented in Table 4 (early data) and Table 5 (final data).

**Table 4. Particle Shedding as a Function of Pump Cycle Rate, Early Data**

| White Knight Model AP100EXT2 | | | | | |
|---|---|---|---|---|---|
| cycles/min | flowrate (liters/min) | cumulative particle concentration (#/ml) | | | |
| | | ≥ 0.050 | ≥ 0.10 | ≥ 0.15 | ≥ 0.20 |
| 49 | 13.3 | 158 | 18.1 | 8.14 | 4.15 |
| 58 | 17.8 | 340 | 68.9 | 33.9 | 17.3 |
| 69 | 22.3 | 954 | 207 | 97.2 | 45.3 |
| 80 | 26.8 | 1980 | 410 | 169 | 76.3 |
| | 31 | | | | |

**Table 5. Second Evaluation of Particle Shedding as a Function of Pump Cycle Rate following 15 days of Steady Operation at 18 liters/min**

| White Knight Model AP100EXT2 | | | | | |
|---|---|---|---|---|---|
| cycles/min | flowrate (liters/min) | cumulative particle concentration (#/ml) | | | |
| | | ≥ 0.050 | ≥ 0.10 | ≥ 0.15 | ≥ 0.20 |
| 49 | 13.3 | 69.6 | 15.7 | 9.60 | 5.45 |
| 58 | 17.8 | 225 | 53.1 | 27.4 | 12.9 |
| 69 | 22.3 | 700 | 166 | 78.1 | 37.9 |
| 79 | 26.8 | 1440 | 311 | 135 | 61.4 |
| 90 | 31 | 2340 | 481 | 195 | 85.6 |

**SUMMARY**

Two White Knight Model AP100EXT2 pumps were received for particle testing and trace metal extraction evaluation. The pump selected for trace metal extraction work was used for setup and shake down of the particle test system, and the pump designated for particle testing (SN P1EXT00102) was used to collect particle-shedding data. The test pump was first flushed at 13.2 liters/min with the air supply disconnected to establish the inherent particle cleanliness of the as-received pump. The pump was then operated at 13.2 liters/min to establish the initial cleanup curve while operating. The flowrate was increased to 16.3 liters/min and the pump was operated for approximately 10 days to establish the long-term cleanup characteristics and determine whether steady-state particle shedding could be achieved in this length of time. A series of flow rates between 13 and 31 liters/min were tested to establish the relationship between quasi-steady-state particle shedding and flow rate.

This pump showed a relatively low level of particle shedding when initially flushed in a passive mode. It added less than 1 particle/ml ≥ 0.1 µm after being flushed with 850 gallons (3200 liters) of water. When operating, particle shedding increased as the cycle rate increased, as expected. A plot of particle shedding versus cycle rate was linear when plotted in log-log space, which appears to be typical of bellows and diaphragm-type pneumatic pumps. Long-term evaluation of particle shedding at an air supply pressure of 40 psig and a flowrate of 16.3 liters/min showed that this pump continued to clean up slowly over many days of continuous operation. Overall, particle-shedding performance was typical of high-quality fluoropolymer pneumatic pumps currently being used in the semiconductor industry.