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Personal Pump Reliability Tester

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A test instrument has been built that measures, displays, and records the flow rate of up to 15 personal sampling pumps. The "Pump Tester" is typically run for eight hours with five or six pumps of one type and displays a graph of flow rate over time for each pump. The flow record for each pump contains up to 240 data points and, although not continuous, provides a useful record of pump performance over long test periods. The numerical flow data can be printed and saved to disk. At the end of the test, the flow-rate graph for each pump is printed. The flow-rate graph can be added to the maintenance and calibration record for the pump to document its performance. Occasionally, erratic pump performance is documented that would not have been detected by flow-rate checks at the beginning and end of an eight-hour period. The Pump Tester can also be used for more formal studies to demonstrate the relative performance of different kinds of pumps under different conditions. Abell, M.T.; Agee, J.P.; Hentz, P.A.; Anastas, M.Y.; Boyd, J.E.: Personal Pump Reliability Tester. Appl. Ind. Hyg. 4:143–146; 1989.

Introduction

The personal sampling pump is widely used for monitoring worker exposure to airborne materials. Whether the measurement is for compliance monitoring or research, it is important that the pump perform reliably. Not only should the pump operate for the duration of the planned sampling period, but the flow rate should also remain constant.

To assure reliable sample collection in the field, a pump maintenance program must include a number of tests.[1] In our laboratory, the standard maintenance procedures include tests that are specific for the type of pump and others that apply to all pumps. As an example of the latter, every pump must meet the manufacturer's specifications for maximum flow rates at given pressure drops. In addition, battery packs are constantly being tested and cycled independently of the pump.[2,3] Finally, in the past, each pump was operated for eight hours and the flow rate checked at the beginning and end of the run. After passing all these tests, approximately 5 percent of the pumps failed in the field.

The final eight-hour check of pumps was successful in detecting some problems not found otherwise, but it could be improved. In an improved test, the flow rate should be measured and recorded more frequently. The test instrument described in this article makes this kind of testing feasible, even when large numbers of pumps are involved. The instrument is referred to as the Pump Tester.

In addition to this routine maintenance check, the Pump Tester can be used for acceptance testing of new pumps or for more formal studies. For example, it may be useful to repeat a 1977 study of pump performance at sub-zero temperatures with current models of pumps.[4] The Pump Tester, connected to pumps in an environmental chamber, could provide more data with less effort than the manual procedure used in that study.

Construction

The Pump Tester was assembled on a laboratory cart (Figure 1) with an Apple II+ computer system on the top shelf, a printer, electronic thermometer, and electronic barometer on the bottom shelf, and all other components on the middle shelf. The latter components include 2 flow sensors, a manifold, 16 three-way electric valves, and 16 relays. The pumps to be tested are hung by their belt clips on a rail around the side of the cart and attached by flexible tubing to the solenoid valves. The following paragraphs contain additional details about these components.

Air flow in the Pump Tester is controlled by valves and a manifold, as shown in Figure 2. Room air enters whichever flow sensor is selected by the manual three-way valve. One flow sensor is for flow rates up to 500 cc/min (Model 565-3-00, Kurz Instruments, Inc., Monterey, CA), the other for flow rates up to 5000 cc/min (Model 565-5-00, Kurz). After air passes the flow sensor and valve, it enters a custom-made, 16-outlet manifold. Air exits the manifold through whichever electric valve (Asco 8320 B3, Automatic Switch Co., Florham Park, NJ) provides a path to a personal sampling pump. Meanwhile, other pumps attached to the system draw air directly from the room through the other side of the electric valves. Valve 16 is special; it is permanently blocked so the system can perform a "zero-check," as described below.

An overview of the Pump Tester's electronic system is shown in Figure 3. The flow sensors are actually electronic mass-flow meters with 0–5 volt electrical output only. Each is connected to one of the 16 channels of a 12-bit analog to digital (A/D) interface card (12 BIT A/D, Applied Engineering, Carrollton, TX) inside the Apple II+ computer. The electronic barometer (MKS Baratron 220AIIS-2A1A-1K, MKS Instruments, Inc., Burlington, MA)

Reference to specific brands, equipment, or trade names in this article does not constitute endorsement by the authors or by the National Institute for Occupational Safety and Health.

FIGURE 1. The Pump Tester as assembled on a laboratory cart with one personal sampling pump at station 1.

and the electronic thermometer (BAT 8, Bailey Instruments, Saddle Brook, NJ) are each connected to a channel of the A/D card. The computer has two disk drives, 64 kilobyte memory, a printer and printer interface card with graphics printing firmware, and a clock card (TimeMaster II HO, Applied Engineering). The computer is an Apple II+, but any Apple II (II, II+, IIe, IIGS) with 64 kilobytes memory could have been used.

The computer controls the experiment by actuating the 16 electric valves one at a time. This is done by encoding the pump number (as a hexadecimal digit) on the four "annunciator" (digital output) lines of the Apple II+ game port. These are connected to a 4-to-16 line decoder (74154 integrated circuit) that was added to the relay (board modified MSL Series, Crydom Division, International Rectifier, El Segundo, CA). The relays (DMP6402A, Crydom), driven by the 5-volt lines from the decoder, switch 110 VAC to the electric valves. A digital I/O interface card with 16 parallel lines could have been used in place of the game port/decoder circuitry chosen. In addition to controlling the electric valves, the computer can measure the electrical output of any of the devices connected to the A/D card.

The cost of duplicating the Pump Tester, excluding the electronic barometer and thermometer, is approximately $4000 for parts and 60 hours construction time. The computer programs are available from the authors, but to function properly, these programs require that the hardware be duplicated exactly.

Calibration and Operation

The software for the Pump Tester is written as several Apple Pascal programs and one short machine language subroutine. When the system is started, a menu provides a choice of 1) calibrating the system, 2) setting the test parameters, or 3) running a test. These choices correspond to running either the CALIBRAT, or PARMWRIT, or PUMPTEST programs. The CALIBRAT program allows the most direct control of the system hardware and is used for calibration and checkout purposes. The PARMWRIT program queries the user for test parameters and records them on disk, and the PUMPTEST program runs the test using those parameters. The PARMWRIT and PUMPTEST programs are not combined because PUMPTEST is already very large. Storing the test parameters on disk provides the advantage of reusing them later should a test need to be repeated. These programs are further described in the following paragraphs on calibration and operation.

Calibration of the Pump Tester's flow sensors required a method of producing constant flow and a fundamental method of flow measurement. Constant flow was obtained by substituting an (critical flow) orifice and vacuum pump in place of one of the personal pumps in Figure 1. The "fundamental" method of flow measurement was an electronic bubble meter, hereafter called "calibrator" (Mini-Buck Calibrator, A.P. Buck, Inc., Orlando, FL). It electronically times the passage of a soap film bubble through a tube of known volume and displays the flow rate. The calibrator is attached to the system ahead of the electronic flow sensors.

The electronic flow sensors are hot-wire devices, and flow measurement is based on thermal conduction. For this reason, the soap-film calibrator was removed from the system while A/D readings were obtained so these flow readings would not be affected by vapors from the soap. Also, since the sensors respond to mass flow whereas environmental monitoring methods require a sample volume (not mass), the effects of temperature and pressure changes on the volume of a mass of air must be taken into account for precise work. As described further in the following paragraphs, the Pump Tester corrects flow rates to the temperature and pressure recorded during the calibration procedure.

The actual calibration procedure employed nine critical flow orifices covering the range of each flow sensor. The "true" flow was measured by averaging ten readings with the calibrator for each critical orifice. Then, the average of ten A/D readings were obtained for that orifice. A/D readings were also obtained for a blocked flow path, that is, a true flow of 0 cc/min. The ten numbered pairs (true, A/D) obtained in this way were stored on

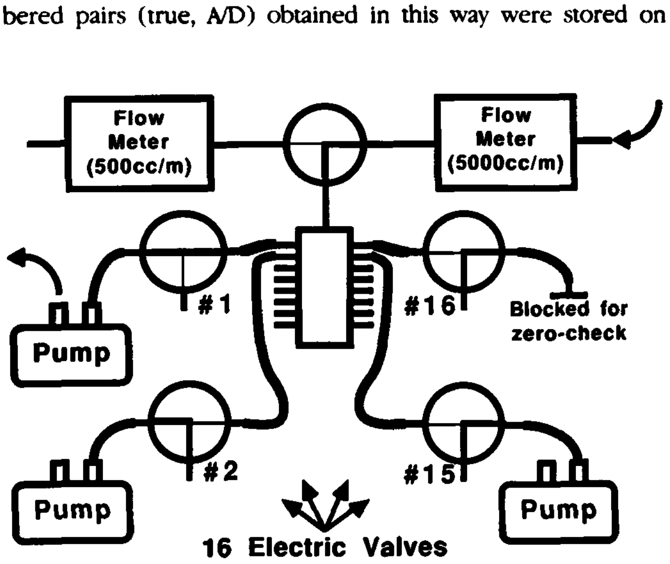

FIGURE 2. Air flow in the Pump Tester system. The computer-controlled electric valves connect only one personal pump at a time to the flow sensor selected by the manual valve. As shown, the high range flow sensor is connected to the pump at station 1.

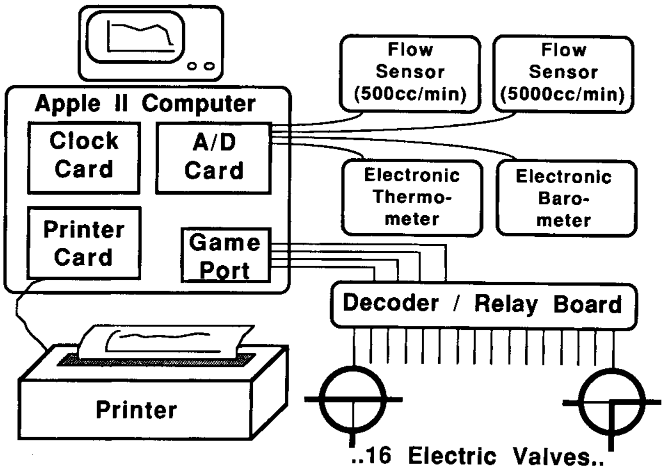

FIGURE 3. The electrical system of the Pump Tester. The software selects a pump (electric valve) with a code sent to the game port, waits for a period of time, then records the flow sensed by the selected flow sensor.

diskette as a "calibration table" for computing flows during normal operation. Included with the calibration table are the temperature and pressure at which the calibration was performed so that flows obtained during tests can be corrected if the test conditions differ from the calibration conditions. The CALIBRAT program facilitated this procedure in the following ways: 1) easy selection of any of the 16 pumping sources; 2) continuously updated display of A/D readings, their running average, the temperature, and the pressure; and 3) easy updating of the calibration table for each flow sensor.

Normal operation of the Pump Tester is defined by the PARMWRIT and PUMPTEST programs. The PARMWRIT program asks for the number of pumps to be tested and allows a label, usually a serial number, to be entered for each pump. It also asks for the maximum flow rate expected and the length of the test in hours. Built into the program are several constants: a 15-second minimum time delay between flow readings and 240 data points to be collected for each pump. Because of these constraints, the length of the test may be longer than requested. Whether the computed length is longer or not, the user is given the opportunity to reenter the parameters. The 15-second delay allows the output of the flow sensor to settle before it is used. The 240 data points were chosen in part because the points fit conveniently on the Apple graphics screen.

The PUMPTEST program begins by reading the test control parameters written to disk by PARMWRIT. Before continuing, PUMPTEST asks the operator if the flow data should be printed or stored on the disk in numeric form during the test, in addition to the graphs that are always printed at the end of the test. It also asks if flow rates should be corrected for temperature and pressure changes. PUMPTEST contains all the instructions necessary for reading the real time clock and timing events; switching the electric valves; initiating A/D readings of flow rate, temperature, and pressure; updating the calibration table after zero checks; calculating flow rates (temperature and pressure corrected, if desired); displaying flow rate graphs; and monitoring the keyboard for operator input.

"Zero checking" means that the A/D output for the flow sensor channel is read while channel 16 (permanently blocked) is activated. If the value read is different from the value in the calibration table, all the A/D values in the table are adjusted to reflect the difference. Temperature and pressure corrections are made to the same temperature and pressure that existed when the flow sensor was calibrated. These corrections are ordinarily small and are not needed for routine work. During the test, the operator can use the keyboard to enter the number of one of the pumps, and the graph of the flow rate for that pump will be displayed. Alternatively, the display will keep changing to show the graph for the pump connected to the flow sensor at that time. Finally, the operator can abort the test before 240 data points have been collected for each pump, and any open disk or print files will be closed, and the graphs produced to that point will be printed.

Results and Discussion

In our laboratory, the Pump Tester is routinely used as the final test of pumps brought in for service, whether scheduled or specially requested. For this purpose, the data are not usually printed or saved to disk since the printed graph of flow rate during the test is excellent documentation of the pump's performance. The graph is attached to the written record kept for each pump that is serviced. Figure 4 combines some typical flow records on one graph. A pump in good condition can maintain a steady flow rate for eight hours, and graph A is typical of such a pump. Sometimes the graph is not quite as smooth as in A but when it approaches B in appearance, there is a problem with the pump.

One of the earliest problems detected in our laboratory by the Pump Tester produced a graph similar to B but with a gradual overall rise with time. The pump had just been serviced, but, since the Pump Tester indicated a problem, it was dismantled and thoroughly checked. Finally, a small fiber, difficult to see with the unaided eye, was detected on the needle valve. When the fiber was removed, the pump performed perfectly. It is likely that the fiber came from a cotton swab used to clean the pump. The pump-cleaning procedure was modified.

Other conditions that can lead to a flow record similar to graph B are flapper valves that will not seat properly, bad pressure switches, and leaks. Investigation into one pump that produced a graph with segments like A interspersed with segments like B turned out to have a very slight leak in a line to a pressure switch. Apparently, the break in the line would alternately open and close, as was verified by flexing the line manually and observing the same effect.

Graph C in Figure 4 was produced by a pump that functioned perfectly on the bench, as the first part of the flow record would indicate. Upon warming up, the pump stopped completely but

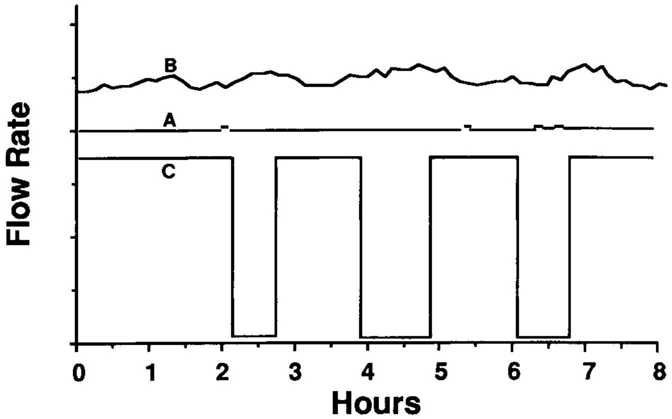

FIGURE 4. Typical flow-rate records for pumps in various conditions: A) pump in good condition; B) erratic flow typical of several kinds of problem (see text); C) interrupted flow caused by bearing that siezes upon heating.

returned to working condition after 30 to 60 minutes. The problem was a bad bearing that would sieze, but only when hot.

Graphs B and C were purposely drawn so that the flow rate at the end of eight hours approximated that at zero hours. That is what actually happens in many cases. The point, of course, is that flow checks at the beginning and the end of an eight-hour test period are no indication that a pump is field-ready. In some cases, the industrial hygienist will observe a pump break down. In other cases, the pump will appear to function but will deliver a volume of air that differs from that calculated by the hygienist. The error may be quite large unless newer pumps are used and the warnings they display are heeded.

The Pump Tester has been extremely useful in our laboratory for these routine performance tests. It has also been used for evaluating new pumps before a purchase. As mentioned previously, the Pump Tester could also be useful for more formal studies of pump performance. However, studies requiring high precision would require additional refinement of the system; the Pump Tester occasionally drifts up to 1.5 percent of full scale during an eight-hour test. The drift occurs in spite of the one-point calibration correction ("zero check") described in the Calibration and Operation section. The authors believe that the addition of a second calibration correction, based on a constant (nonzero) flow, would decrease drift to less than 0.5 percent.

Recommendations

To achieve reliable field operation of personal sampling pumps, every organization should have a maintenance program that includes a means of checking the work. The final check of overall pump performance should consist of an eight-hour test with continuous, or frequent, recording of flow rate. The check should be performed each time a pump is serviced, which will vary from six months to two years, depending on the type of pump and its usage. Small organizations can use a strip-chart recorder and electronic flow sensor to record flow rates during performance checks. When a large number of pumps must be maintained, a test system similar to the one described here may be justifiable. Without this kind of testing, critical data may be lost, or worse, erroneous data may be reported.

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