AN AIR-FILTER SENSOR FOR HOME-USED AIR CONDITIONERS

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Abstract

This paper presents a successful senior project of instrumentation developed in a Mechanical Engineering Technology senior capstone course. Students were encouraged to approach the problem of designing an air-filter sensor and to propose an optimum and practical solution for the problem. Work includes conceptual design and analysis, implementation, tests and modifications.

When an air filter is used in a home air conditioner, inhabitants often forget when to replace it until the cooling or heating capacity is obviously reduced. If the filter remains in service, the efficiency of the cooling/heating system will continue decreasing while the electricity bill will significantly increase. In some worst cases, the air quality will also be affected. This paper presents an idea of designing and fabricating an air-filter sensor to alleviate this problem. The sensor will send a warning signal when the filter collects a specific amount of dust in the air filter. It can be easily installed and only consumes a negligible amount of electricity. A photo sensor with an infrared LED emitter and receiver is used in this design. As the infrared LED can transmit through most of the home-used air filter to its receiver, a signal will be sent out when a specified amount of dust is collected in the filter and the light is blocked from the emitter to the receiver. The emitter and receiver are mounted on a simple fixture and can be easily fitted on an air filter. In addition, cost analysis of using the sensor show that it can save a significant amount on an electricity bill, when filters are replaced properly.

I. Introduction

A vital part of engineering technology education is the use of senior design (capstone) projects to provide students with the opportunity to apply knowledge gained in other courses to solve a design problem. Mechanical engineering technology students at Old Dominion University usually take such a course in their last semester of study. Small groups of students (usually two) work on projects identified from one of several sources. A primary source of projects is local industry, usually small in size. Many of these companies do not have the engineering staff to investigate new products or make major improvement in their manufacturing processes. Contacts with these companies may be initiated by faculty members, the company itself, the college's Technology Application Center (an in-house organization that specializes in promoting economic development for the region through matching industry needs with faculty expertise, student resources and university facilities), or by students themselves who may be working for one of the companies. While student projects may vary substantially, they must all contain certain elements: design analysis, computer generated drawings, vendor contact, literature search for products and manufacturing techniques, material selection and if possible prototype manufacture and testing. The project described in this paper was brought to the faculty members through a regional director of the Virginia's Center for Innovative Technology (a sponsoring agency at the Technology Application Center).

II. Description of the Project

When a clean air filter is installed in a heating, ventilation, and air conditioning (HVAC) system, people usually forget to replace it, because it does not significantly affect the operation of an HVAC system. However, when the air filter becomes dirty and remains unchanged, the air quality will worsen and efficiency of the HVAC system will also be reduced. Since there is no paper or patent discussing this issue, a senior project team was formed to investigate this problem and to design an air-filter sensor for a home-use HVAC system. Two teams worked on the project. Team 1 consisting of three students performed the design analysis and fabricated the components[2]. The second team consisting of one student performed air quality tests, cost analysis and testing[3].

Primary objectives of the project are as follows:

1. Measure the difference between the in-door air quality when using a clean and a dirty air filters.
2. Measure the increase in power consumption when using a dirty filter.
3. Design a reliable, low cost sensor, which will be able to send a warning signal when an air filter gets dirty.
4. Design a simple installation method for the sensor.
5. Perform a cost analysis for the implementation of the device.

1. Air quality tests

The major purpose of installing an air filter in a home-use HVAC system is to block the dusty air particles from the incoming air and to remove contaminants introduced into the re-circulated air from conditioned space[1]. When a new filter is just installed, it provides little resistance to the airflow. The low resistance provides little friction loss in the system, thus requires less energy for the air mover (fan) than a system with a dirty filter. A clean air filter can also produce a better air quality during the same operation time period of a HVAC system. To measure the change of the airflow between a clean filter and a dirty filter, s simple apparatus was developed by students in the MET program [2,3]. A rectangular box contains a fan and motor with openings at the fan discharge and suction ends. The suction end had provisions for the installation of a standard small HVAC filter and a solid sliding gate that could cover all or portions of the entrance.

Figure 1 shows the apparatus with a filter and 50% of its area blocked. The centrifugal fan used in this test is driven by a ¾ HP Westinghouse motor. Results of the initial tests are recorded in Table 1, where the average airflow velocity dropped from 820 ft/min with no blockage to 40 ft/min with a blockage of 75% of its total area. The average velocity was measured at the discharge openings, which was the same size as the filter. The current draw of the fan motor was 10.9 amps for a clean filter and dropped to 9.2 amps for 75% blockage[3]. Table 2 shows the result of comparison tests performed using a clean filter and a dirty filter[3]. In these 11 tests, the average current draw was 11.0 amps when using a clean filter and 10.5 amps when using a dirty filter. The average airflow velocity was 833 ft/min for a clean filter and 677 ft/min for a dirty filter.

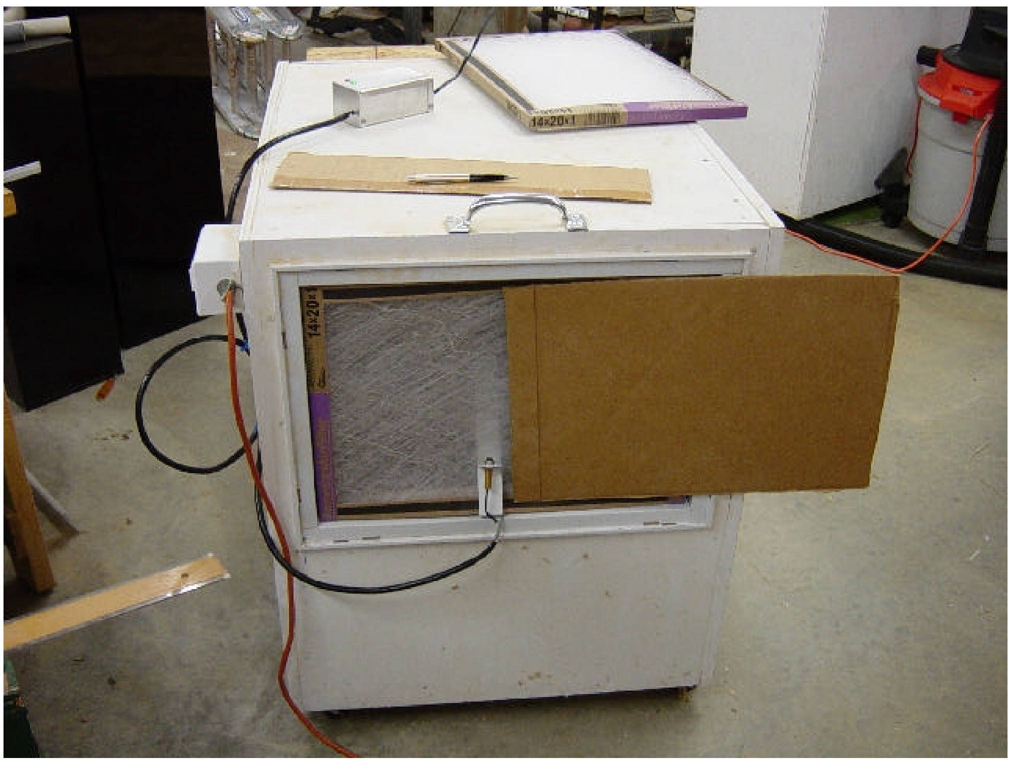

Figure 1: Tests when an air filter is blocked by 50% of its area.

Filter Blockage	Current draw (amps)	Air velocity (ft/min)
No blockage	10.9	820
25 percent blocked	10.1	520
50 percent blocked	9.6	470
75 percent blocked	9.2	40

Table 1: Results of tests from Figure 1.

Test No.	Current Draw (amps)	Air Velocity (ft/min)
Test 1 with clean filter	10.4	800
Test 1 with dirty filter	10.0	670
Test 2 with clean filter	10.7	830
Test 2 with dirty filter	10.4	690
Test 3 with clean filter	11.0	770
Test 3 with dirty filter	10.5	670
Test 4 with clean filter	10.8	820
Test 4 with dirty filter	10.3	670
Test 5 with clean filter	11.2	850
Test 5 with dirty filter	10.7	680
Test 6 with clean filter	10.9	830
Test 6 with dirty filter	10.6	720
Test 7 with clean filter	11.1	870
Test 7 with dirty filter	10.6	680
Test 8 with clean filter	11.1	830
Test 8 with dirty filter	10.6	660
Test 9 with clean filter	11.4	840
Test 9 with dirty filter	10.2	610
Test 10 with clean filter	11.2	840
Test 10 with dirty filter	10.6	710
Test 11 with clean filter	11.3	870
Test 11 with dirty filter	10.6	690
Average for clean filter	11.009	832.82
Average for dirty filter	10.464	677.273

Table 2: Results of current draw and airflow when using a clean filter and a dirty filter.

Measurements of the air quality are performed by using a Terra Universal Particle Concentration Meter (PCM)[4], which counts the number of dusty air particles with the diameter of the dusty particle greater than 3 microns within a cubic foot. The results of the experiments performed by students are given in Tables 3 and 4. Table 3 shows that a clean air filter can reduce the number of dusty particles to 77%, while Table 4 shows a dusty filter can only reduce to 41.5%[3].

Air Quality Test No.	Initial PCM reading (ppm)	PCM reading 2.5 hrs later (ppm)	Difference	Percent difference
1	667,800	187,500	480300	71.9
2	1,111,100	226,800	884,300	79.6
3	649,000	135,900	513,100	79.1
4	518,200	77,400	440,800	85.1
5	67,300	36,000	31,300	46.7
6	108,100	45,800	62,300	57.6
7	129,200	31,000	98,200	76
Average	**3,250,700**	**740,400**	**2,510,300**	**77.2**

Table 3: Air Quality test results using a clean filter.

Air Quality Test No.	Initial PCM reading (ppm)	PCM reading 2.5 hrs later (ppm)	Difference	Percent difference
1	78,500	63,000	15,500	19.7
2	109,500	63,500	46,000	42
3	118,700	73,800	44,900	37.8
4	124,800	71,600	53,200	42.6
5	141,400	81,500	59,900	42.4
6	110,200	61,500	48,700	44.1
7	138,600	65,400	73,200	52.8
Average	**821,700**	**480,300**	**341,400**	**41.5**

Table 4: Air Quality test results using a dirty filter.

2. Power consumption

Calculation of the difference on the power consumption between clean and dirty air filters can also be based on the information provided by Table 2. In these tests, the average airflow of a clean air filter and a dusty filter are approximately 832 ft/min and 677 ft/min respectively, and the current draws are 11.0 and 10.5 amps respectively. The time to "clean" the same amount of air is longer for the dirty filter than the clean one by a factor of 832/677 or 1.23, which is used in the power consumption calculations. When the fan motor is running in an actual HVAC system, a current draw of 25 amps is also assumed in a heating or cooling unit. It is also assumed that the power factor of the fan motor is one for both types of runs. The power factor is most likely the same for both types of runs. It is possibly less than one, which reduces the energy savings slightly. When considering five operational hours a day for a 30-day period, the monthly energy bill is calculated as follows:

Unblocked filter power cost calculations:

P = Power
I = Current
V = voltage
Power Consumption / Sec = P = IV = (11.009 + 25) x 120 = 4321.08 joules /Sec
Power Consumption / Hr = 4321.08 x 3600 sec/hr = 1.55559 x 10^7 Joules/hr
Power Consumption / Month = 1.55559 x 10^7 x 150 hrs = 2.33 x 10^9 Joules = 648 KWH.
Energy Cost = \$0.10 per KWH,
Energy Cost /Month = 648 x 0.10 = \$64.80

Blocked filter power cost calculations:

Power Consumption / Sec = P = IV = (10.464 + 25) x 120 = 4255.68 joules /Sec
Power Consumption / Hr = 4255.68 x 3600 sec/hr = 1.53 x 10^7 Joules/hr
Power Consumption / Month = 1.53 x 10^7 x 1.23 x 150 hrs = 2.83 x 10^9 Joules = 785 KWH.
Energy Cost = \$0.10 per KWH,
Energy Cost /Month = 785 x 0.10 = \$78.50

In this case, savings for using a clean air filter is about $13.70 per month, which is about 20% of the total HVAC bill in this case.

3. Design of the air-filter sensor

Design of the air-filter sensor includes Objectives 3 and 4 of this project. The design was performed by a group of students[2]. The sensor must be reliable and also easy to install. One of the designs proposed by students (Team-1) included installation of a pair of differential pressure cells mounted on the either side of the air filter. When the pressure drop reaches a specified value, a signal will be sent out to activate a warning LED or light. This design, however, needs a significant number of calibrations on the sensors for different types of HVAC systems. It also requires special techniques when installing the sensor on the HVAC system. The reliability of this design is another concern.

Since home-use air filters are generally translucent, the faculty advisors proposed another design using a photoelectric sensor for this purpose. The design includes a light emitter and receiver. The light emitter emits a beam of light and the receiver detects the amount of light that passes through the filter. If the receiver cannot receive enough of the beam of light or if the light is completely blocked, the sensor will send a signal out to activate the red LED, which is a warning signal. Figure 2 is assembled in the opposed sensing mode and Figure 3 is in the

Figure 2: Opposed sensing mode.

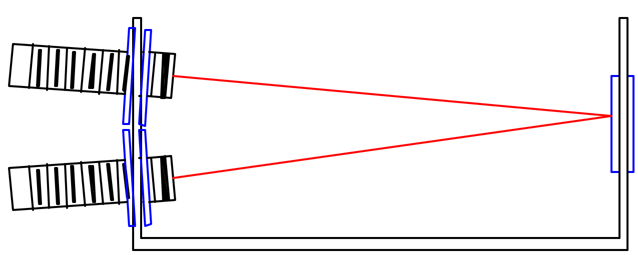

Figure 3: Retro-reflective sensing mode.

retro-reflective sensing mode. According to the information from Banner Engineering Corporation[4], opposed mode sensing is the most efficient sensing mode, and offers the highest level of sensing energy to overcome atmospheric contamination and sensor misalignment. Retro-reflective sensing mode, however, can be applied when the space on one side is limited. The beam pattern emitted from the emitter can cover a circular area with an approximately five-inch diameter. With an excess gain on the light, the beam intensity can be increase up to 150 times with an opposing distance of 1 ft. Therefore the reliability of the device is very high. In this design, a pair of Banner Engineering[4] LR 400 (emitter) and PT 400 (receiver) are assembled and tested.

Banner Engineering Corporation also provides the circuit required with a MPS 15 power supply board and a MA 3-4 modulated photoelectric RS8 socket amplifier. A simple bracket is designed so that it can be fitted to most of the home-use HVAC units. Figure 4 shows the design of the sensor. When the light from the emitter is not blocked, a green LED is set to be on. Figure 5 shows that the red LED is on when the filter becomes dirty. The total cost of this prototype design is less than $200.00. This cost can be substantially reduced in a mass-production environment.

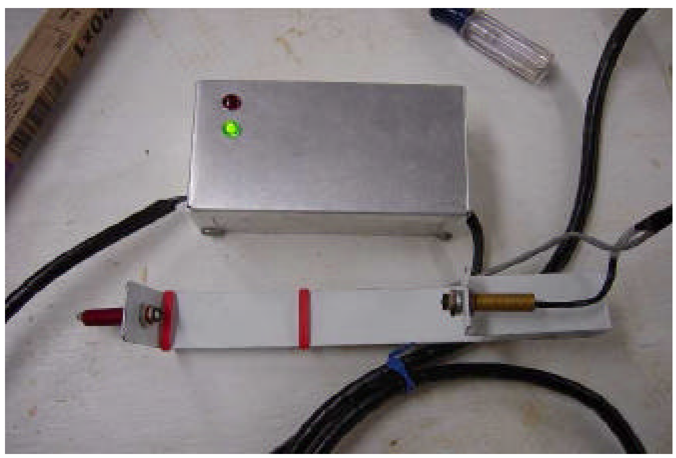

Figure 4: Air-filter sensor with green LED on with no blockage of light.

Figure 5: Air-filter with Red LED on with the blockage of the light.

Cost of energy consumption for this sensor is as follows:

Power Consumption / Sec = P = IV = 8.17 x 10^{-3} x 120 = 0.98 joules /Sec
Power Consumption / Hr = 0.98 x 3600 sec/hr = 3529 Joules/hr
Power Consumption / Month = 3529 x 720 hrs = 2.54 x 10^{6} Joules = 0.705KWH.
Energy Cost = $0.10 per KWH,
Energy Cost /Month = 0.705 x 0.10 = $0.07

Results show that the electric bill per month for using the sensor is negligible.

III Summary

This project presents a way for engineering technology students to study and solve the problem of when to replace the air filters of a home-use HVAC unit. The sensor was designed and tested. Preliminary tests show that, if a dirty filter is not replaced, then the indoor air quality will worsen, as the filter loses its function. In addition, a dirty filter will also increase the energy bill, because the airflow will be significantly reduced when compared to that of a clean air filter. The sensor presented in this paper is very reliable and can be fitted easily to most home-use air filters, which are translucent. The cost of the sensor can be reduced to less than $100.00 when in mass production and the energy consumed by the sensor is only about 7 cents a month. The calculated energy savings by using clean filters is approximately $14 per month, making the cost of the device recoverable in less than a year possible.

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Biography

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Cheng Y Lin is an Associate Professor of Engineering Technology at Old Dominion University. Dr. Lin is a registered Professional Engineer of Virginia. He teaches Machine Design, CAD, CNC, and Robotics and is active in local industrial research and consultation. He earned his B.S. and M.S. degrees of Mechanical

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