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Design and Application of Duct Leak Detection Instrument in the Aircraft Pneumatic Systems

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ABSTRACT: The pneumatic manifold system pipes on airplanes contain air with a pressure of approximately 45 psi and a temperature of approximately 117ºC. This pipe stretches from the tip of the right wing to the tip of the left and continues to the tail area of the aircraft. The total length of pipe reaches up to 300 meters. The diameter of the pipe reaches a size of up to 7 inches. Pneumatic system duct leaks are very dangerous because they affect aircraft performance and high temperatures can damage components around the leak and can even cause a fire. So far, if a leak is detected, it takes a long time to find the area because the detection method is still manual and visual. For this reason, a heat detection instrument was designed to find leak points in the pneumatic system channels. It is hoped that this instrument can help the process of finding leak points more quickly. The detection results of the instrument after testing its function using a heat sensor show more accurate results because the heat sensor can detect in areas that cannot be seen visually. This detection instrument is also able to measure the overheat temperature level at two stages, namely at 60°C and 100°C.

KEYWORDS: Pneumatic System, Auxiliary Power Unit, Air Starter Unit, duct leaks, Heat Detection Instrument

I. INTRODUCTION

Airplanes are one of the important means of transportation nowadays. There are more and more companies operating in the air transportation sector. Along with the intense competition in the air transportation business, companies operating in the air transportation sector are required to improve service quality and punctuality. Likewise, in the aircraft maintenance industry, the availability of aircraft that are timely and airworthy/safe is very much needed by aircraft service users. Therefore, reliable technicians and accurate test instruments are needed to support the smooth maintenance of aircraft.

Pneumatic system pipe leaks are very dangerous because they affect aircraft performance. High temperatures can damage components located around the leak and can even cause a fire. Leaks can be identified by a decrease in air pressure in the pipe and can be seen from an indication of air pressure of less than 45 psi in each of these three areas[1]. If a leak occurs, test it by smearing the channel with a soap-like liquid and visually observing the foam that forms at the leak point. Therefore, the instrument was created to find the leak point using another method, namely utilizing the heat energy generated from the hot air that comes out around the leak point. This hot air causes the surrounding temperature to rise.

II. GENERAL OVERVIEW OF PNEUMATIC SYSTEMS

The pneumatic system on an airplane originates from the engine, or Auxiliary Power Unit (APU) before the engine starts. This system is really needed for: starting the engine, air conditioning, cabin/cargo heating, driving the flight control/air steering system, anti-ice/preventing a layer of ice from forming on certain surfaces and sensors, and much more. The pneumatic manifold system channels contain pressurized air of approximately 45 psi and a temperature of approximately 117ºC. This pipe is divided into 3 parts, namely: right wing, left wing and tail area.[1][2]

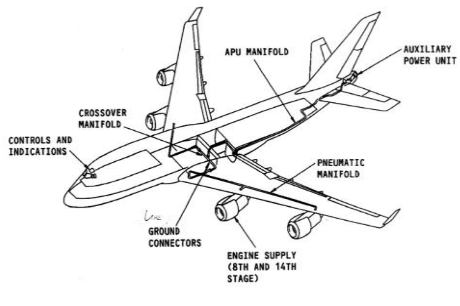

Figure 1. Pneumatic system channels on airplanes

The sources of the pneumatic system on an aircraft, namely the internal part, consist of the engine during flight and the Auxiliary Power Unit (APU), which is used only for maintenance and starting the engine. Meanwhile, the external pneumatic source consists of the Air Starter Unit (ASU), used during maintenance or replacement of the APU to start the engine if the APU is not functioning. The total length of the pipe can reach 300 meters. The diameter of the pipe reaches sizes up to 7 inches. The pneumatic system on airplanes is really needed, namely from heat energy and air pressure.

To protect the system from leaks, regular maintenance is carried out on the pneumatic system channels every 2000 flying hours, namely inspections and replacement of seals according to the manufacturer's instructions. If a leak is detected, it takes a long time to determine the leak point because it uses a visual method, namely looking for air that is sprayed out, by smearing the surface of the pipe with a liquid such as soap. If a leak occurs, it will react to produce foam. During maintenance in the workshop and the Auxiliary Power Unit does not function to obtain pneumatic power, ground equipment is used, namely a compressor that is separate from the aircraft. This compressor can produce pneumatic power almost the same as that produced by an airplane engine, namely a pressure of more than 40 psi and has an output temperature of between 60°C - 200°C. This equipment is called the Air Start Unit (ASU). The lowest temperature limit of 60°C is used as the temperature level to determine the occurrence of leaks. Meanwhile, the highest temperature limit uses a temperature limit of 100°C because the highest temperature allowed is up to 117°C [1].

The aircraft system protects by closing the pneumatic distribution system if it exceeds this temperature to prevent further damage. In the area around the aircraft engine, specifically the pylon/mount area where the engine is installed, there is an overheat sensor of around 100°C which provides an early warning to the aircraft crew.

Therefore, an instrument was designed with a method of utilizing hot air leaks which can increase the surrounding temperature. The instrument is expected to be able to detect heat around pneumatic duct leaks which are limited to two temperature conditions, namely 60°C and 100°C. The instrument is designed with the following specifications:

- Battery powered, light and removable.
- 4 sensors that can detect simultaneously.
- Can detect overheating at two stages, namely 60°C and 100°C.
- There are many components for the instruments on the market so it is not difficult to design and maintain.

III. DESIGN AND REALIZATION

A. Design Concept

To make the time to find leaks more efficient, a detection instrument was designed which has 4 sensors that work simultaneously at 4 measurement points. Apart from that, it is equipped with a battery power supply which is contained in the detection instrument box so that it can be easily removed.

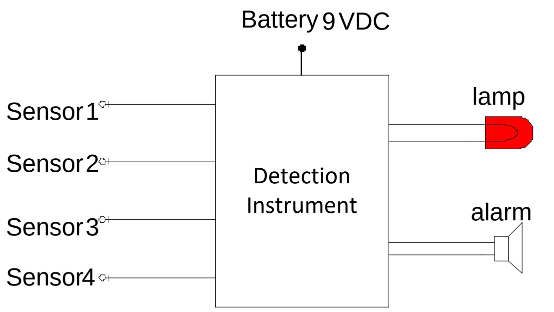

Figure 2. Concept of Heat Detection Instrument

Figure 2 shows the concept of a heat detection instrument. This instrument works if the sensor detects overheating, the indication light will light up and be accompanied by an alarm sound. To obtain two measurement results, the detection device circuit is equipped with a selector switch which can measure two levels of overheat temperature. The low overheat level is 60°C and the high overheat level is 100°C.

B. Design of a heat Detection

The overall overview of instrument design is as shown in Figure 3. In designing this instrument heat detection, there is a 9 DC volt battery power supply circuit, $5V_{DC}$ voltage regulator, indicator circuit including lights (LED) and buzzer, detector circuit and heat sensor. The power supply circuit produces an output of 5 V_{DC} providing power in the form of $5V_{DC}$ voltage to the indicator circuit and heat detection circuit. The temperature received by the sensor will be detected by a detector circuit by setting the overheat level according to the selected selector, namely 60°C or 100°C. If one or more sensors detect the selected overheat level, the detector circuit will activate the indicator circuit to turn on the light followed by an alarm sound. To get the desired design, components are selected that support the performance of the circuit so that it can work well. It is hoped that the difference between the calculation results and the series to be created is the same as or not too far from the theoretical calculation.

This design includes aspects of determining the circuit, selecting components and possibilities for development. The design aims to ensure that the instrument is made according to the desired specifications.

The overall circuit of the Heat Detection Instrument consists of 3 circuit blocks, namely:

1. Power Supply Circuit
2. Heat Detection Circuit
3. Indicator Circuit

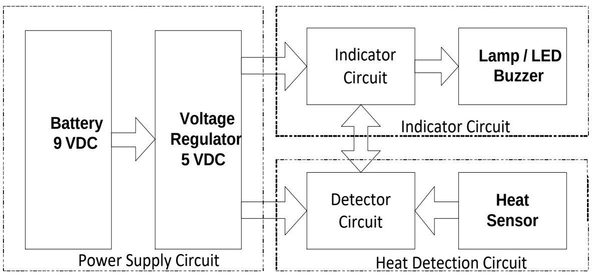

Figure 3. Block Diagram of Heat Detection Instrument

C. Power Supply Circuit

A 9 V_{DC} battery is used because it is adapted to the needs of the instrument. Most circuits use a voltage of +5 V_{DC} while the IC 7805 requires a minimum input voltage of 7-8 V_{DC} [3][4]. If used on an airplane, power is available in the test instrument itself, so it is removable and can be used in difficult areas. The voltage required for the heat detection circuit and indicator circuit is +5V_{DC} so an LM7805 voltage regulator is added.

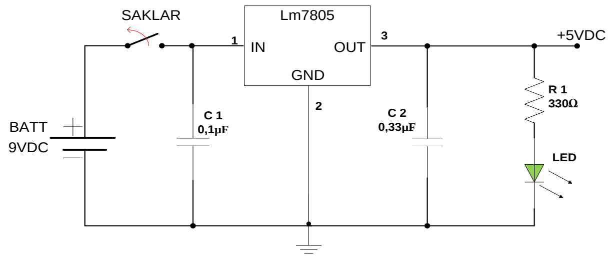

Figure 4 Power Supply Circuit

Figure 4 shows a schematic diagram of a +5V_{DC} power supply which is used as a power supply for another circuit block. Part of this block consists of a 9 Volt battery, added a regulator IC for voltage stabilization, a safety circuit, and an indicator in the form of an LED. The LM7805 IC is useful for regulating the positive output voltage of 5volt DC. This type of regulator was chosen because of its ability to regulate a very stable voltage. On the output side there is a capacitance of 0.1µF to avoid voltage changes due to changes in load. 0.33µF capacitance on the input side of the regulator to avoid ripples if the filtering is far from the regulator[5]. This circuit is also equipped with an LED to indicate that the battery power is on and provides an output voltage of +5 V_{DC}. To prevent the LED from being quickly damaged by providing a maximum voltage drop of about 3.4 V on the LED, a resistance R is installed. Assuming the current is around 5 mA, the value of the resistance R_1 is:

$$R1 = \frac{5v - 3{,}4v}{0.005\ A} = 320\Omega$$

The resistance that is often found on the market is 330Ω. So the voltage that falls on the LED is 5V-1.6V=3.4V.

D. Heat Detection Circuit

The Heat Detection Circuit consists of: 4 detectors, along with the LM35 heat sensor, CA 3130 Op-Amp and BC547 Transistor as a switch. To obtain two stages of measurement, a 4PDT selector is used, namely a switch with four inputs, each consisting of two output options. The values of the fixed resistance R_1 or R_2 can determine the overheat level point which is determined and controlled by the 4PDT switch [6][7].

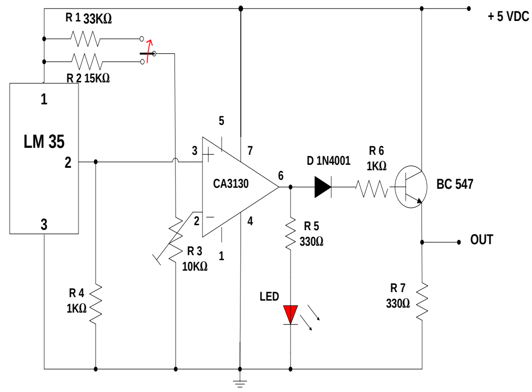

Figure 5. Detector Circuit

The detector circuit uses 4 sensors to be able to test at 4 points, thus speeding up the testing process because it can detect 4 points at the same time.

The LM 35 heat sensor has a sensor capability that scales linearly with the measured temperature, namely 10 millivolts per 1 degree Celsius [8]. Because it is made in two stages, a selector is added to the Op-Amp input as reference voltage to get the voltage as a comparator, namely 600mV to get an overheat value of 60°C and 1 V to get an overheat value of 100°C. Because the number of detectors is four, to simplify, only one selector is used, namely a 4PDT type switch, namely 4 inputs with two outputs each.

The selector can be positioned in two stages, namely to measure the lower overheat level temperature (60°C), and it can also measure the higher overheat level temperature (100°C).

In the detector circuit there is also a resistance R4 of 1 KΩ to eliminate false/measurement errors due to the threshold voltage. The LED is used as an indication of +5 V_{DC} power, as in the power supply circuit the LED is installed with a resistance R_5 of about 330 Ω so that the LED does not get damaged quickly. Diodes are used to avoid reverse current from a series of detectors which are paired in parallel as many as 4 pieces. When one or more of the LM 32 sensors overheats, the Op-Amp works and creates a Hi output of 2.2V, causing the transistor to work into forward bias and supply voltage to the next circuit, namely the indicator generator circuit.

E. Voltage divider circuit

The working principle of an operational amplifier (Op-Amp) is to compare the values of the two inputs (inverting input and non-inverting input), if both inputs have the same value then the Op-Amp output is zero (zero) and if there is a difference in the values of the two inputs then the output is Op-Amp will provide the output voltage[9]. Because the non-inverting input has been obtained from the sensor, the inverting input is used as the reference voltage.

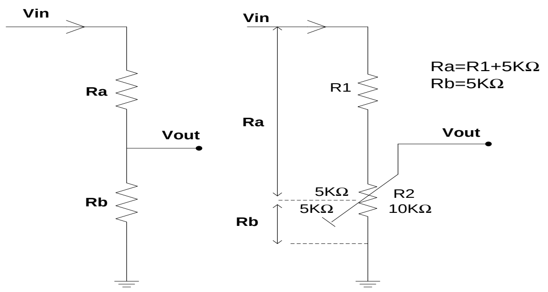

Figure 6. Voltage Divider Circuit

To obtain the same voltage as the output from the sensor, 3 resistors are used, namely a variable resistor called R_2 and a fixed resistor R_1 to measure the low overheat level (60°C), while R_2 is for the high position (100°C). The variable resistor can be determined first, namely 10 KΩ, so that the middle value can be taken, namely 5 KΩ.

From fig. 6 it is known that the resistance Ra = R_1+5KΩ, V_{IN} = 5 V and V_{OUT} = 600mV. By using equation 1 [10]. we get Ra = 36,666 Ω and R_1 = 31,666 Ω. For this reason, a fixed resistance R_1 of 32KΩ is used.

$$V_{out} = V_{in}\,\frac{R_b}{R_a + R_b} \quad \dots\dots\dots\dots (1)$$

In the same way, for high temperatures, the resistance R_a = R_2+5KΩ and the voltage V_{IN} = 5 V, V_{OUT} = 1V are used to obtain resistance R_a = 20,000 Ω and R_2 = R_a – 5000 Ω = 15 KΩ. For this reason, a resistance R_2 of 15 KΩ is used which is available on the market and is not difficult to obtain.

F. The indicator generator circuit

The indicator generator circuit consists of IC 555 as an ASTABLE MULTIVIBRATOR circuit, at the output a buzzer is installed as an alarm and an LED. As in the previous circuit, a 330Ω R_3 resistance is added before the LED to reduce the voltage drop on the LED to +3.4 V_{DC}, so it doesn't get damaged quickly.

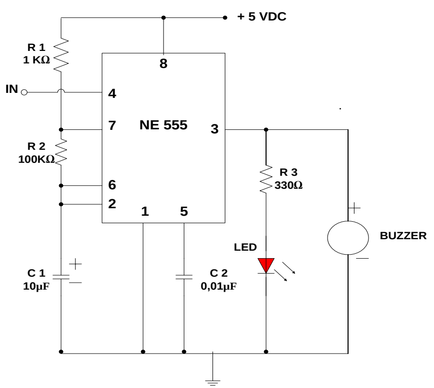

Figure 7. Indicator Circuit

If IC 555 pin 4th gets voltage from the detector circuit, then IC 555 is set up into ASTABLE MODE (clock) to activate the buzzer. The components R_1, R_2, and C_1 act as frequency regulators, which ultimately also regulate the tone/rhythm of the buzzer and LED[8][9]. The frequency and duty cycle can be determined by the quantities R_1 (1 KΩ), R_2 (100 KΩ), and C_1 (10µF). The duty cycle and frequency are given as

$$t_{LO} = 0.693\ x\ R_2\,C_1 \quad \dots\dots\dots\dots (2)$$

$$t_{HI} = 0.693\ \times (R_1 + R_2)C_1 \quad \dots\dots\dots (3)$$

$$Duty\ cycle = \frac{t_{HI}}{t_{HI} + t_{LO}} \quad \dots\dots\dots\dots (4)$$

$$frequency = \frac{1}{t_{HI} + t_{LO}} \quad \dots\dots\dots\dots (5)$$

From the previous equations, the duty cycle is 50.24 % and the frequency is *f* = 0.71791 Hz.

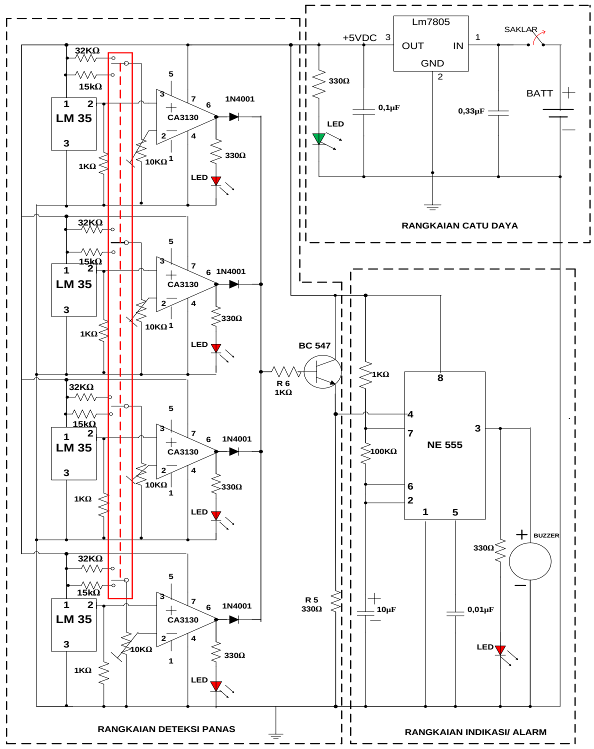

Figure 8. Schematic of Heat Detection Instrument

The power supply circuit sourced from a 9V_{DC} battery is reduced by a voltage regulator to 5V_{DC} output. This circuit is equipped with lights and switches to indicate that the battery is active. The power supply circuit provides voltage for the heat detection circuit and indicator circuit to work. The detector circuit uses 4 sensors to be able to test at 4 points, thus speeding up the testing process because it can detect 4 points at the same time. Each heat detection circuit is equipped with a light to determine which sensor is detecting heat. If one/more heat sensors detect a predetermined temperature level where the overheat temperature is determined to be 60°C, the Op-Amp will work to provide current to the transistor which functions as a switch to activate the indicator circuit so that the light turns on and the buzzer will sound.

IV. REALIZATION AND TESTING OF HEAT DETECTION INSTRUMENT

After the design process is complete, the instrument is realized and a box measuring 12 x 8.5 x 5 cm is installed. LEDs are installed on the surface of the box as an indication. There are two switches, namely the switch to activate the battery with a green light indication, indicating that the instrument has received power from the battery. The second switch is a selector for selecting the overheat temperature level of 60°C or 100°C.

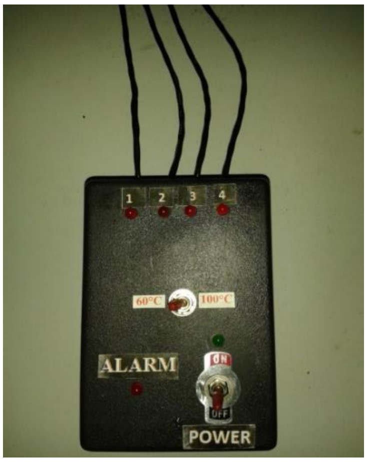

Figure 9. Realization of Heat Detection Instrument

As shown in Figure 9, it is hoped that this instrument can detect four pneumatic system channel points simultaneously, so that it can speed up testing time. If there is noise during the test so that the buzzer/alarm cannot be heard, you can see the indication light on the box panel.

The purpose of measurement, testing and analysis is to find out to what extent the theoretical design results can be implemented in reality so that the design results of this instrument can be used for heat detection testing in aircraft. The tests and measurements carried out are:

1. Measurement of the sensor output voltage is converted to the actual air temperature and the deviation and accuracy seen.
2. Measure the output of the detector circuit, whether it detects heat or not, to determine whether the detector is functioning as expected and that there are no false indications.
3. Test the function of the heat detection instrument to determine whether the heat sensor, detector and indicators are functioning properly.
4. The test instrument used is:
   - FLUKE 189 S type Digital Multimeter
   - FLUKE 50S type Digital Thermometer
   - Heat/hot gun.
5. Environmental conditions at the time of testing:
   a) Location: Avionics Workshop PT. GMF-AEROASIA
   b) Room temperature: 28°C
   c) Humidity: 63%

G. Heat Sensor Testing

The purpose of heat sensor testing is to determine the accuracy and deviation of the sensor, it is hoped that the tolerance will be no more than 0.25°C. The accuracy of the sensor can affect the success of subsequent testing. This sensor functions as a converter from the physical quantity of temperature to the quantity of voltage which has a coefficient of 10 mV/°C, which means that an increase in temperature of 1 °C will result in an increase of 10 mV. The test procedure is by connecting a +5 V_{DC} power supply to V_{CC} or by turning on the battery. Figure 10 only shows one sensor, the other sensors are not depicted but use the same method of measurement. The measurement point is located at pin 2/output of the LM 35 sensor. Every 1°C increase will show a voltage of 10 mV. Heat the sensor using a heat gun to the temperature used as the level measurement point, are: 35°C, 40°C, 45°C, 50°C, 55°C, 57°C and 60^0C, measure the temperature using a thermometer. Connect a Digital Multimeter to the test point (TP), and record the output of each sensor as in Fig. 11. The measurement results are in table I.

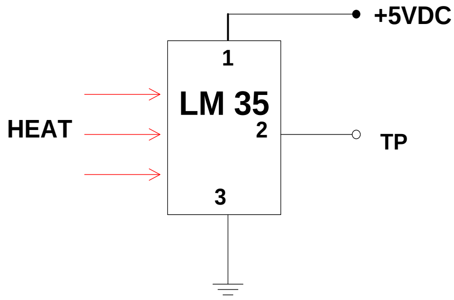

Figure 10. Temperature sensor test point (TP)

Figures 11 show a comparison between the temperature and the output voltage at a temperature of 60.1°C. The test results and measurements of the 1st - 4th heat sensors (figure 11) are made into table I.

The comparison between temperature and voltage can be calculated using equation 6.

V_{LM35} = Temperature x 10 mV ………. (6)

Table I. Tests on Temperature Sensors

Temp °C	1st Detector		2nd Detector	
	TP1 (mV)	Deviation °C	TP3 (mV)	Deviation °C
35.3	352	0,1	352,5	0,05
41.0	408	0,2	409	0,1
45,2	450	0,2	451,5	0,05
50,5	504	0,1	503	0,2
55,3	552	0,1	552	0,1
60,1	599	0,2	599	0,2
62,0	619	0,1	619	0,1
Temp °C	3rd Detector		4th Detector	
	TP3 (mV)	Deviation °C	TP4 (mV)	Deviation °C
35.3	352,5	0,05	352	0,1
41.0	409	0,1	408,5	0,15
45,2	451,5	0,05	451	0,1
50,5	503	0,2	502	0,3
55,3	552	0,1	552	0,1
60,1	599	0,2	598,5	0,25
62,0	619	0,1	619	0,1

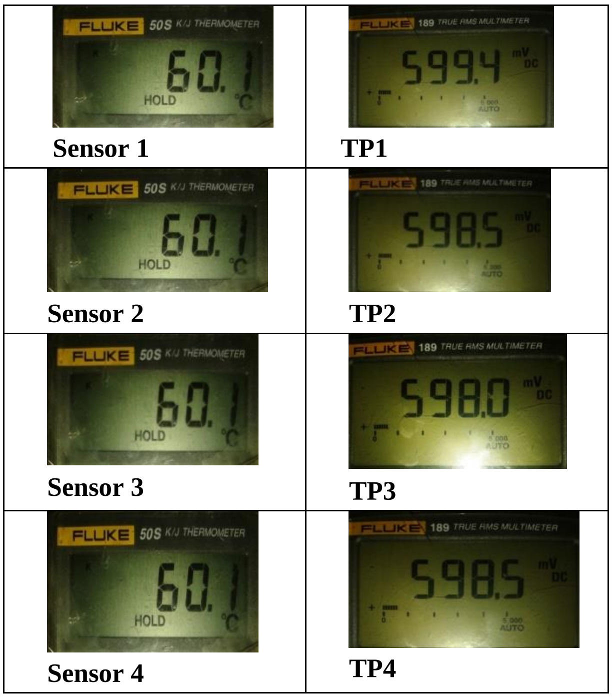

Figure 11. Testing the heat sensor at a temperature of 60°C and the output results

The deviation is obtained from the calculation results minus the measurement results, shown in table I. Each detector has its own tolerance value. The average deviation on 1st detector is 0.14, meaning it has a tolerance value of 0.14. In the same way for sensors on 2nd detectors, 3rd detectors and 4th detectors respectively the tolerances are: 0.18; 0.11; and 0.17. If we average it, we get an average temperature deviation of 0.15. So the accuracy of the test instrument is found to have a tolerance of 0.15 °C

H. Instrument Function Testing

The purpose of testing the function of the tool is to find out how the heat detection tool works if one or more sensors detect heat. Testing the function of the tool was carried out in two stages, namely testing the Lo switch position at an overheat temperature level of 60°C and the Hi switch position at a temperature level of 100°C. The implementation is almost the same, the only difference is the overheat temperature level, that is, if the switch is placed in one position, the four detectors will measure only one overheat temperature level. For example, if the selector is placed in the Lo position, the four detectors will measure the overheat temperature level at 60°C, and if the switch is placed in the Hi position, all four detectors will measure the overheat temperature level at 100°C.

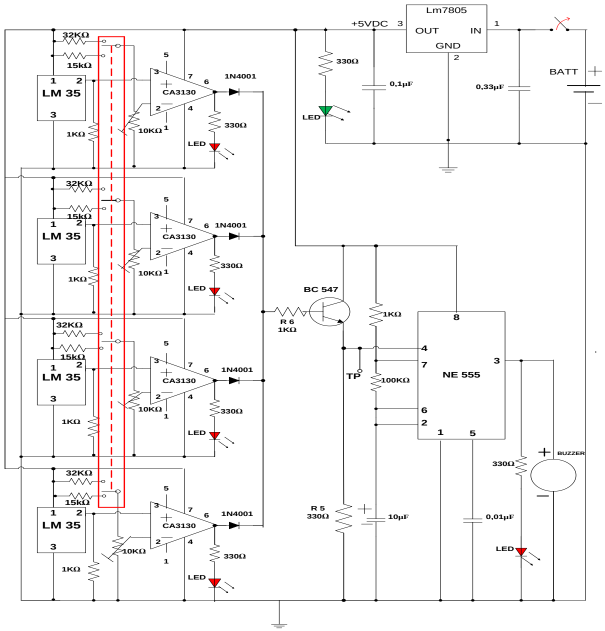

Figure 12. Testing Points in Instrument

The measurement point for testing the function of the instrument is set at the output of the BC547 transistor. If overheating is detected, it is hoped that the output voltage on the transistor as a switch will continue to function well regardless of the number of sensors detected, either one or more. So that indications and alarms also function if one or more sensors detect overheating. The test is by looking at the lights and the alarm is on. The test procedure is to heat the sensors one by one or simultaneously until overheating occurs. For the switch in the Low level position, the overheat temperature is 60°C. Then measure the voltage at the measurement point and observe the lights and alarms. The output of the transistor is called TP and is used as a measurement point. Each detector is indicated by an LED light, namely L1 for detector 1, L2 for detector 2, L3 for detector 3 and L4 for detector 4. Testing will show which detectors are active or detect heat and their effect on the output voltage of the BC547 transistor as a switch. And to observe the magnitude of the output voltage if more than one detector is active at the same time. The indicator circuit can be observed by looking at the alarm indication lamp called L5 which will light up if one or more detectors detect overheating. Followed by a buzzer sound as an alarm, from the results of the observations, table II was created which can provide information about whether the heat detection instrument is functioning.

Table II. Detection Instrument Function Test Results at a Temperature of 60°C

Detector	Temp (°C)	TP Vdc	L1	L2	L3	L4	L5	alarm
-	60	0	0ff	0ff	0ff	0ff	0ff	0ff
1	60	1,53	on	0ff	0ff	0ff	on	on
2	60	1,54	0ff	on	0ff	0ff	on	on
3	60	1,53	0ff	0ff	on	0ff	on	on

4	60	1,55	0ff	0ff	0ff	on	on	on
1,2	60	1,45	on	on	0ff	0ff	on	on
1,3	60	1,45	on	0ff	on	0ff	on	on
2,4	60	1,47	0ff	on	0ff	on	on	on
1,2,3	60	1,39	on	on	on	0ff	on	on
1,2,3,4	60	1,35	on	on	on	on	on	on

The results of the instrument function test can be concluded that each detector light is functioning well, as evidenced by the light turning on according to the detector that actively detects overheat, namely L1 for detector 1, L2 for detector 2, L3 for detector 3 and L4 for detector 4. Voltage on the BC547 transistor output functions well, where there is no large voltage drop when a load is applied, namely with one or more detectors working simultaneously, even up to all four detectors working. For the lights and buzzer, it proves that the indicator circuit is functioning properly. When one or more detectors detect overheat, the L5 light lights up and the buzzer sounds. To test the function of the instrument, the switch in the high position is almost the same, the only difference is in the overheat temperature level, namely at a temperature of 100° C. The measurement point for the instrument function test is still set at the output of the BC547 transistor. If overheat is detected at around 100° C, the output voltage on the transistor is expected as the switch still functions well, regardless of the number of sensors detected. So the indicator functions if one or more sensors detect overheating. The test is carried out by looking at the lights and alarms on. The test procedure involves heating the sensors one by one or simultaneously until overheating occurs. For the switch in the High level position, the overheat temperature is 100°C. Then measure the voltage at the measurement point and observe the lights and alarms. The output of the transistor is called TP and is used as a measurement point. Each detector is indicated by an LED, namely L1 for detector 1, L2 for detector 2, L3 for detector 3 and L4 for detector 4. Testing will show which detectors are active or detect heat and their effect on the output voltage of the BC547 transistor as a switch. And also to observe the magnitude of the output voltage if more than one detector is active at the same time. The indicator circuit can be observed by looking at the alarm indication lamp called L5 which will light up if one or more detectors detect overheating. Followed by a buzzer sound as an alarm, from the results of the observations, table III was created which can provide information about whether the heat detection instrument is functioning.

Table III. Detection instrument Function Test Results at a Temperature of 100°C

detektor	*Temp (°C)*	*TP Vdc*	*L1*	*L2*	*L3*	*L4*	*L5*	*alarm*
-	100	0	0ff	0ff	0ff	0ff	0ff	0ff
1	100	1,51	on	0ff	0ff	0ff	on	on
2	100	1,54	0ff	on	0ff	0ff	on	on
3	100	1,52	0ff	0ff	on	0ff	on	on
4	100	1,53	0ff	0ff	0ff	on	on	on
1,2	100	1,37	on	on	0ff	0ff	on	on
1,3	100	1,39	on	0ff	on	0ff	on	on
2,4	100	1,41	0ff	on	0ff	on	on	on
1,2,3	100	1,35	on	on	on	0ff	on	on
1,2,3,4	100	1,34	on	on	on	on	on	on

The results of testing the function of the tool show that each detector light is functioning properly as evidenced by the light turning on according to the detector that actively detects overheat, namely L1 for detector 1, L2 for detector 2, L3 for detector 3 and L4 for detector 4. Voltage at the transistor output The BC547 functions well because there is no large voltage drop even when more than one detector is loaded simultaneously. Even all four detectors worked. For the lights and buzzer, it proves that the indication/alarm circuit is functioning properly when one or more detectors detect overheating, the L5 light lights up and the buzzer sounds.

CONCLUSIONS

Based on the results of testing, calculations and analysis that have been done, it can be concluded:

1. The measurement results for each circuit block do not occur, all components work according to the expected specifications. The sensor measurement results showed that the average error deviation from the four sensors was less than 0.25°C, namely 0.15°C. At the 60°C position selector, if it detects heat of 60°C or more, the indication light comes on followed by an alarm in the form of a buzzer. Likewise, at the 100°C position, if it detects heat of 100°C or more, the indication light comes on followed by an alarm in the form of a buzzer.
2. The instrument can be used to detect heat at two temperature levels, namely an overheat level of 60°C and an overheat level of 100°C. The instrument can be used to detect pneumatic system duct leaks more quickly than using the previous visual method. The results of testing function showed that the heat detection instrument was functioning properly.

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