

[54] **INFERRED MEASUREMENT OF THE
TURBINE INLET TEMPERATURE OF A GAS
TURBINE ENGINE**

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[22] Filed: **Feb. 22, 1972**

[21] Appl. No.: **227,620**

[52] U.S. Cl. **73/343 R**, 60/39.28 R, 73/344,
73/346, 235/151.3, 235/196

[51] Int. Cl. **G01k 7/02**

[58] Field of Search 73/346, 343, 345, 359, 344;
60/39.28; 235/92 CP, 92 MT, 92 FL, 92 DM,
196, 151.3, 151.34

[56] **References Cited**
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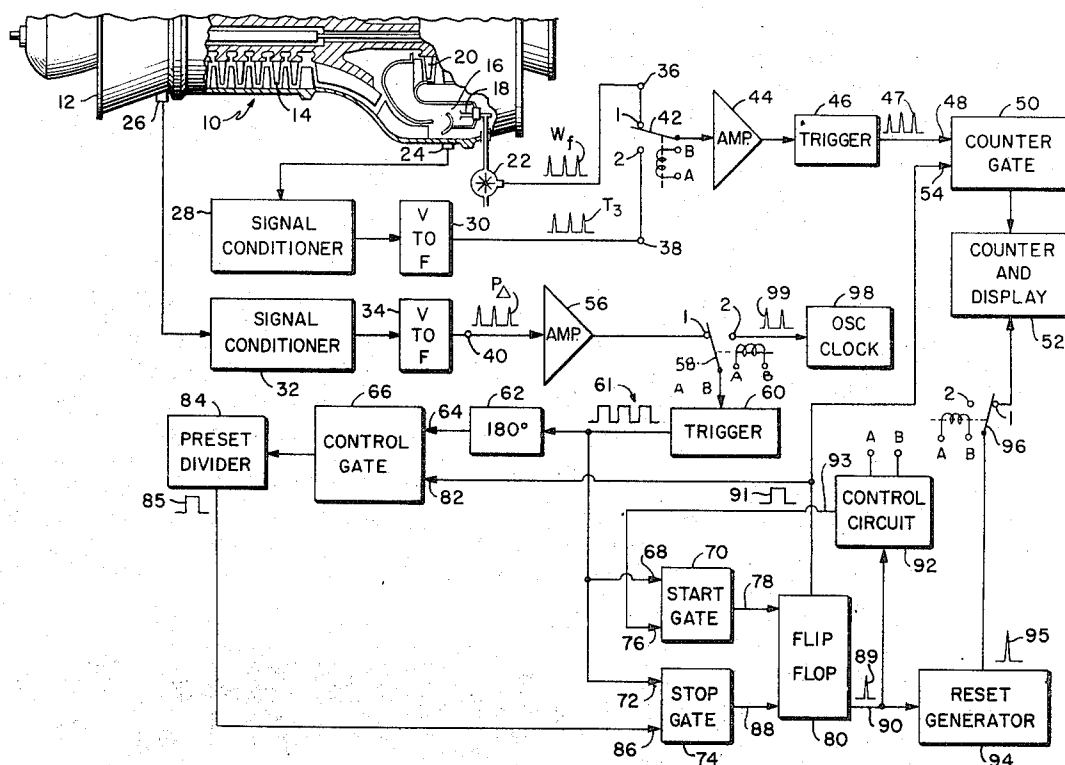
Assistant Examiner—Denis E. Corr

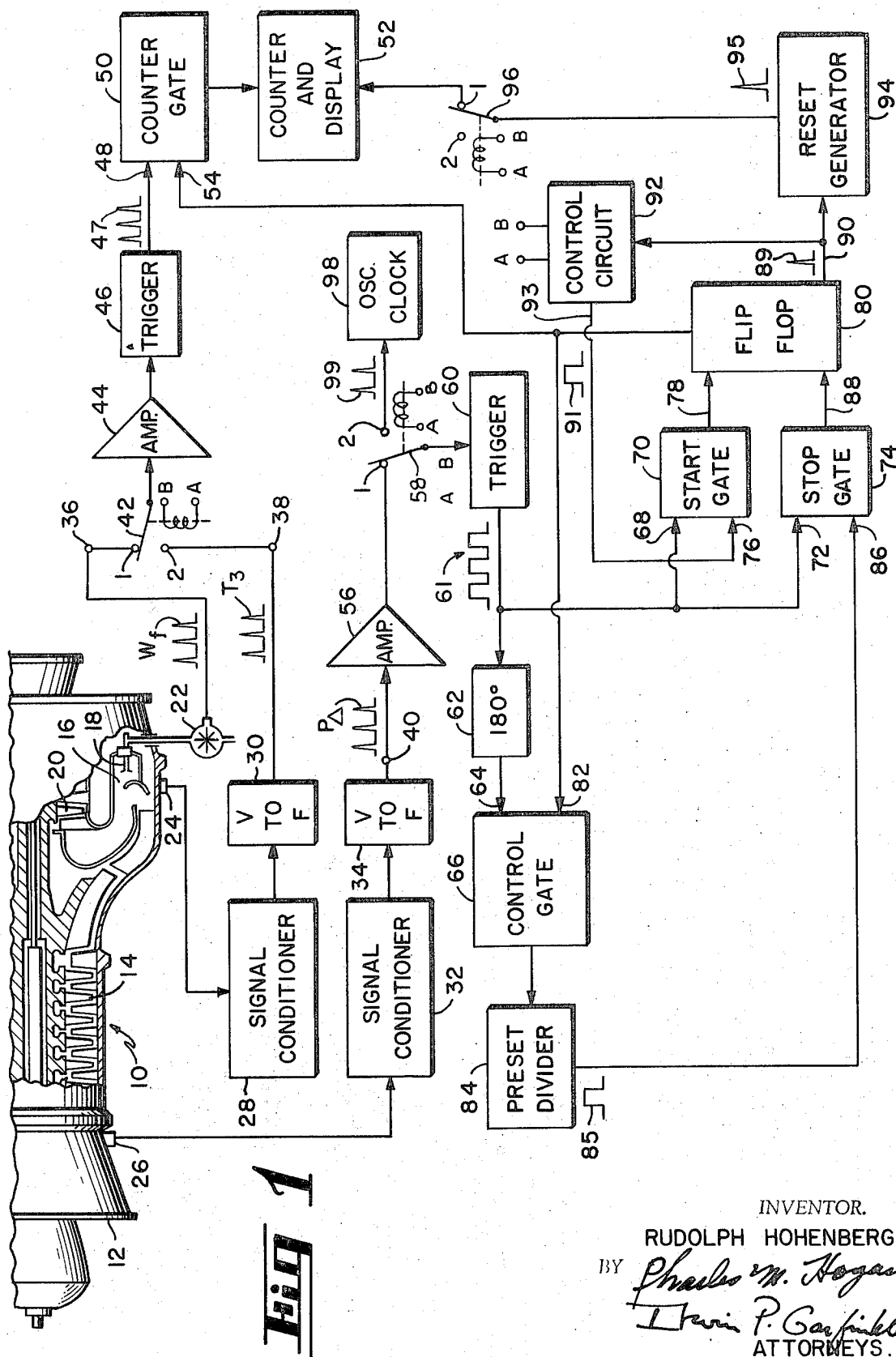
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[57] **ABSTRACT**

Turbine inlet temperature of a gas turbine engine is determined by solving the equation $T_5 = C'W_f/P_{\Delta} + T_3$, where T_5 is the gas producer turbine inlet temperature, W_f is the fuel flow, C' is essentially a constant determined by the type of fuel (but varying slowly with changes in ambient pressure), P_{Δ} is the difference between the static pressure in the bellmouth inlet to the compressor and the ambient pressure, and T_3 is the compressor outlet temperature. T_5 is computed by developing three analog frequencies representing W_f , P_{Δ} , and T_3 , respectively. The division W_f/P_{Δ} is accomplished by counting the number of pulses generated by W_f during the occurrence of a given number of pulses representing P_{Δ} . Thereafter the system counts and adds the number of pulses representing T_3 generated during a clocked period.

9 Claims, 2 Drawing Figures





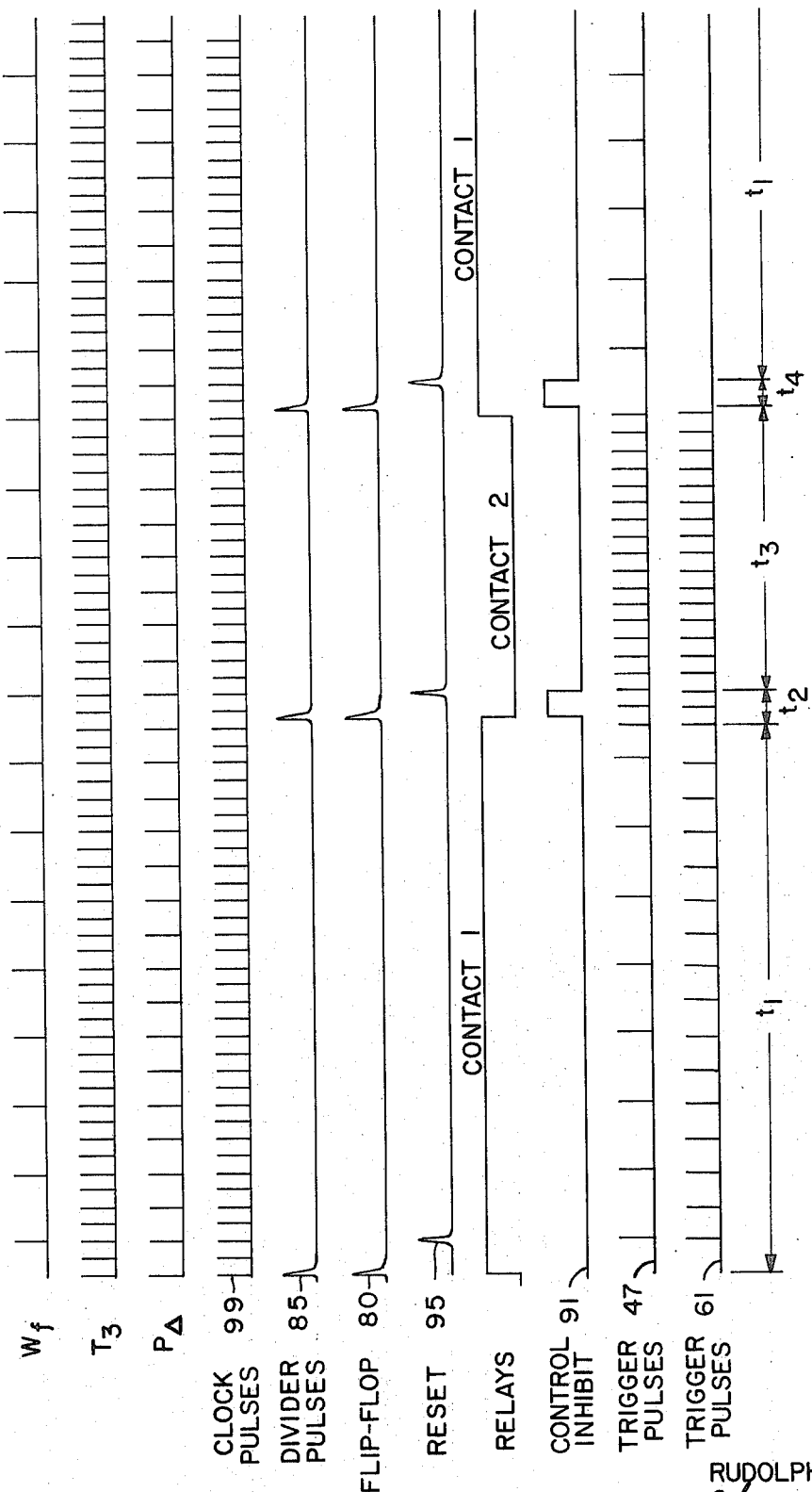


FIG. 2

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INFERRED MEASUREMENT OF THE TURBINE INLET TEMPERATURE OF A GAS TURBINE ENGINE

BACKGROUND OF THE INVENTION

It is known that the expression $C(W_f/W_a) + T_3$ fairly represents T_5 , where T_3 is the gas producer turbine inlet temperature of a gas turbine engine, W_f is the fuel flow, W_a is the air flow, and T_3 is the compressor outlet temperature. It has also been determined that $W_a = K(P_\Delta/P_{amb})$, where P_Δ is the difference in pressure between ambient pressure and the pressure measured at the bellmouth inlet to the compressor, P_{amb} is ambient pressure, and K is a constant. Since ambient pressure changes very slowly, the foregoing equation can be approximated as $W_a = K'P_\Delta$. Therefore the expression $C(W_f/W_a) + T_3$ can be rewritten as $C'(W_f/P_\Delta) + T_3 = T_5$. This invention converts each of the parameters of the above equation to an analog frequency and provides the means for computing and displaying T_5 .

THE DRAWINGS

FIG. 1 illustrates a practical embodiment of the invention; and

FIG. 2 is a series of curves demonstrating the operation of FIG. 1.

DESCRIPTION OF THE ILLUSTRATED EMBODIMENT

FIG. 1 of the drawing shows a gas turbine engine 10 with which the present invention is used. The engine has an inlet bellmouth 12 for the entry of air into a compressor 14 which pressurizes the air for discharge to a combustor 16. A series of nozzles 18 receive fuel from a fuel system (not shown) for injection into the combustor 16. The resultant fuel air mixture is ignited by conventional means and the exhaust gases pass through a gas producer turbine 20. The turbine 20 is connected to the compressor so that a portion of the energy from the gas stream is used to drive the compressor. The discharge from the turbine 20 may be directed across a power turbine (not shown) to develop a rotating output or through a nozzle for a reaction propulsion output.

The system provides a fuel flow transducer 22 positioned in the fuel line to the nozzles 18. The fuel flow transducer is conventional and produces signal voltage pulses W_f having a frequency which is a direct function of the quantity of fuel flowing through the nozzles. In addition, the system provides a thermocouple 24 located in the after portion of the compressor diffuser and a pressure transducer 26. While the transducer 26 is shown positioned within the engine bellmouth 12, it will be understood that its function is to produce a signal P_Δ proportional to the static bellmouth pressure and the ambient pressure. The thermocouple 24 develops a direct voltage signal which is a function of the compressor outlet temperature T_3 .

The direct voltage signal generated by the thermocouple 24 is applied through a signal conditioner 28 to a voltage-to-frequency converter 30. Similarly, the direct voltage generated by the pressure transducer 26 is applied through a signal conditioner 32 to a voltage-to-frequency converter 34. Thus, pulses W_f , T_3 and P_Δ having frequencies proportional to fuel flow W_f , compressor outlet temperature T_3 , and difference pres-

sure P_Δ , respectively, are developed at terminals 36, 38, and 40, respectively.

The W_f pulses appearing at the terminal 36 are applied through a relay-operated switch 42 in its initial contact 1 position (as shown) to an amplifier 44 and a trigger 46. Each pulse applied to the input of the trigger 46 produces one pulse at its output, and these trigger pulses 47 are applied to one terminal 48 of an AND gate referred to herein as the counter gate 50. The output from the counter gate 50, if any, is applied to a counter and display 52. However, an output is developed from the counter gate 50 only when an appropriate voltage is applied to the second input gate terminal 54. Such a voltage is developed at terminal 54 for a period of time which is a function of the difference pressure P_Δ .

The output pulses P_Δ from the voltage-to-frequency converter 34 are applied from the terminal 40 through an amplifier 56 through a relay-operated switch 58 in its initial contact 1 position to a trigger 60. The trigger 60 develops one output pulse for each pulse applied to its input. The trigger output pulses 61 are applied simultaneously to three gates as follows: first, through a 180° phase shifter 62 to a one input terminal 64 of a control gate 66; second, to an input terminal 68 of a start gate 70; and third, to an input terminal 72 of a stop gate 74. The start gate 70 is set up to pass any voltages applied to its input terminal 68 so long as an inhibiting voltage is not present at its inhibit terminal 76. Initially no such inhibit voltage is present, and therefore the first pulse applied to the input terminal 68 of the start gate 70 from the trigger 60 is applied to the input terminal 78 of flip-flop 80. This causes the flip-flop 80 to change state and provides two enabling voltages, one for the terminal 54 of the counter gate 50, and in addition, for the second input terminal 82 of control gate 66. Therefore the counter gate 50 and the control gate 66 are simultaneously enabled.

With the gates 50 and 66 open to pass applied signal, the output from the trigger 46 (representing the pulse output from the fuel flow transducer 22) is applied to the counter 52, while, at the same time, the pulse output from the trigger 60 (representing the pulse rate proportional to the difference pressure, i.e., W_f/P_Δ) set divider 84.

It is intended that the counter gate 50 be disabled when the preset divider 84 is filled, since this would provide to the counter 52 the number of pulses representing the fuel flow developed during a period of time proportional to the difference pressure, i.e., W_f/P_Δ . For this purpose, when the preset divider 84 has been filled, an output pulse is developed and applied to the terminal 86 of the stop gate 74. This enables the stop gate 74 and passes an output pulse from the trigger 60 to the second input terminal 88 of the flip-flop 80. This serves to change the state of the flip-flop 80. When flip-flop 80 changes state, the counter gate 50 and the control gate 66 are disabled. In addition, when the flip-flop 80 changes state, a pulse 89 is generated from it at line 90 and simultaneously applied to a control circuit 92 and a reset generator 94.

Application of the pulse 89 from line 90 to the control circuit 92 causes control circuit 92 to drive simultaneously each of the relay-operated switches 42 and 58 from their contact 1 positions to their contact 2 positions, and, in addition, to drive a relay-operated reset switch 96 from its initial contact 1 position to its

contact 2 position. Control circuit 92 also provides a short duration inhibit pulse 91 at line 93 to the inhibit terminal 76 of the start gate 70.

The application of pulse 89 from the flip-flop 80 to the reset generator 94 develops a reset pulse 95 which is delayed (by internal circuitry not shown) until after the operation of the reset relay switch 96. It will be seen, however, that the reset pulse 95 developed by the reset generator 94 cannot be applied to the counter and display 52 until after the reset switch 96 has been returned to its contact 1 position, and therefore the counter is not reset, nor is the count displayed.

When the switch 42 is in its contact 2 position, the T_3 pulses from the voltage-to-frequency converter 30 are applied through the switch 42 and amplifier 44 to the trigger 46. The trigger pulses 47, one for each T_3 pulse, are applied to the input terminal 48 of counter gate 50. Similarly, with the switch 58 in its contact 2 position, the clock output pulses 99 of a fixed frequency oscillator clock 98 are applied to the trigger 60.

The first of the output pulses 61 from the trigger 60, following the termination of the inhibit pulse from the control circuit 92, passes through the start gate 70 and again reverses the state of the flip-flop 80. As before, the output of the flip-flop 80 in its first state enables the counter gate 50 and the control gate 66. Thus, the T_3 pulses are counted in the counter 52 until the preset divider 84 is filled. This time, however, the divider 84 is filled after a fixed period of time since it is supplied at the rate of the fixed frequency oscillator clock 98.

The filling of the preset divider 84 provides a pulse 85 to the terminal 86 of stop gate 74, thereby enabling gate 74 to permit the passage of the next trigger pulse 61 from the trigger circuit 60 to the input terminal 88 of flip-flop 80. This causes the flip-flop to change to its second state and to generate an output pulse 89 at line 90 which is applied to the control circuit 92 and to the reset circuit 94. Changing to the second state disables the control gate 66 and the counter gate 50 to stop the counts. The application of a pulse from line 90 to the control circuit 92 serves to cause control circuit 92 to drive each one of the relay switches 42, 58, and 96 from their contact 2 positions to their contact 1 positions and to provide a short duration inhibit pulse at line 93 for the terminal 76 at the start gate 70. As before, the application of a pulse at line 90 from the flip-flop 80 to the reset generator 94 develops a delayed reset pulse. This time, however, the switch 96 is in its contact 1 position, and the reset pulse developed by the reset generator 94 is applied to the counter 52. This displays the counter and resets the counter to zero, and permits the cycle to repeat.

OPERATION OF THE INVENTION

The operation of the invention may better be understood by reference to FIG. 2 which shows the output pulses developed within the various functional circuits of FIG. 1. While in FIG. 2 the number of generated pulses shown has been arbitrarily selected for ease of presentation and do not reflect the numbers that would be used in a practical system, the relationships between the pulses generated in different circuits are representative of a working system.

A series of pulses W_f , T_3 , and P_Δ are developed from the outputs of the fuel flow transducer 22 and the voltage-to-frequency converters 30 and 34, respectively. While pulses W_f , T_3 , and P_Δ are shown as having

been developed at a fixed rate, it will be understood that the numbers of pulses generated actually vary with fuel flow, temperature, and pressure. The clock output pulses 99 from the oscillator clock 98 are always developed at a fixed clock rate.

With the relay switches 42 and 58 in their initial contact 1 position, the W_f pulses are applied to the trigger 46 so that the trigger 46 begins to develop trigger pulses at a rate equal to W_f . At the same time the P_Δ pulses are being applied to the trigger 60 and since the control gate 66 is initially uninhibited, the P_Δ pulses are applied to the preset divider 84.

FIG. 2 assumes, by way of example, that the preset divider 84 is set for 16 counts. Therefore, a preset divider output pulse 85 is produced after the generation of 16 P_Δ pulses. The time at which 16 P_Δ pulses are produced is, of course, dependent on the magnitude of the difference in pressure between the static bellmouth pressure and ambient pressure, and determines the duration of time t_1 .

When the preset divider output pulse 85 is applied to the terminal 86 of the stop gate 74, it causes the flip-flop 80 to change state. This serves to disable the counter gate 50 and the control gate 66, and during this period t_2 the output from the trigger 46 is not passed to the counter and display 52.

The flip-flop 80 also has an output to the control circuit 92 which serves to drive the relays from their contact 1 position to their contact 2 positions. This serves to connect the clock pulses 99 and the T_3 pulses to the triggers 60 and 46, respectively.

However, further counting is held until the control inhibit pulse 91 terminates. After that time the first output pulse from the trigger 60 passes through the start gate 70 to change the state of the flip-flop 80 and resume the count. This time, of course, the count is made of the T_3 pulses (during period t_3) until such time as the preset divider is filled by the clock output pulses 99. At the filling of the preset divider 84, the flip-flop 80 changes state and generates a reset pulse 95. This time the switch is in its contact 1 position and the counter is reset and the count is displayed. The cycle then repeats.

Thus, during period t_1 a count is made of the number of W_f pulses generated during the time it takes to generate 16 P_Δ pulses. This number represents W_f/P_Δ and the design of the system, including the selection of the preset number for the preset divider 84 and the frequency of the oscillator clock 98 establishes the C' factor. During the period t_2 the entire system is held and no count is permitted. During the period t_3 the system counts the number of T_3 pulses produced during a fixed time period required to count 16 clock pulses 99. This count represents temperature T_3 . At this point, the counter contains the number of pulses representing the gas producer inlet temperature $T_5 = C' (W_f P_\Delta) + T_3$. During the period t_4 the system displays the total count and resets, and the cycle repeats.

Various modifications and adaptations will be apparent to persons skilled in the art. It is intended, therefore, that the invention be limited only by the appended claims as interpreted in the light of the prior art.

I claim:

1. In combination with a gas turbine engine having an air inlet bellmouth for delivering air to the inlet of an air compressor, said air compressor delivering compressed air from its outlet to a combustor supplied with

fuel through a fuel line, and a turbine driven by the gases delivered at its inlet from the outlet of said combustor, means for determining the inlet temperature of said turbine, said means comprising:

- means for generating a first signal comprised of first pulses having a pulse repetition rate proportional to the rate of flow of fuel through said fuel line;
- means for generating a second signal comprised of second pulses having a pulse repetition rate proportional to the magnitude of the difference in pressure between the static pressure in said bellmouth and ambient pressure;
- means for generating a third signal comprised of third pulses having a repetition rate proportional to the temperature in said compressor outlet;
- means during a variable first time period inversely proportional to the repetition rate of said second pulses for counting the number of said first pulses generated during said first time period;
- means during a fixed second time period for counting the number of said third pulses generated during said second time period; and
- means for summing the numbers of said first and third pulses counted during said time periods and for displaying the summation thereof.

2. The invention as defined in claim 1 wherein said variable first time period is established by means of a preset divider, said second pulses being applied to said divider, said first time period being equal to the time required to fill said preset divider.

3. The invention as defined in claim 2 wherein said fixed second time period is established by means of a clock oscillator, said oscillator having an output comprised of pulses having a fixed pulse repetition rate, said pulses being applied to said preset divider, said second time period being equal to the time required to fill said preset divider.

4. In combination with a gas turbine engine having an air inlet bellmouth for delivering air to the inlet of an air compressor, said air compressor delivering compressed air from its outlet to a combustor supplied with fuel through a fuel line, and a turbine driven by the gases delivered at its inlet from the outlet of said combustor, means for determining the inlet temperature of said turbine, said means comprising:

- fuel flow transducer means in said fuel line for generating a fuel flow signal comprised of first pulses having a first pulse repetition rate proportional to the rate of flow of fuel through said fuel line;
- a pressure transducer for generating a pressure signal having a voltage magnitude proportional to the magnitude of the difference between the static pressure in said bellmouth and ambient pressure;
- means for converting said pressure signal to second pulses having a second pulse repetition rate proportional to the magnitude of said static pressure;
- a temperature transducer positioned in said compressor outlet for generating a temperature signal having a voltage magnitude proportional to the temperature in said compressor outlet;
- means for converting said temperature signal to third pulses having a third pulse repetition rate proportional to the magnitude of said temperature;

means during a variable first time period inversely proportional to said second pulse repetition rate for counting the number of said first pulses generated during said first time period;

means during a fixed second time period for counting the numbers of said third pulses generated during said second time period; and

means for summing the numbers of said first and third pulses counted during said periods and for displaying the summation thereof.

5. The invention as defined in claim 4 wherein said variable first time period is established by means of a preset divider, said second pulses being applied to said divider, said first time period being equal to the time required to fill said preset divider.

6. The invention as defined in claim 5 wherein said fixed second time period is established by means of a clock oscillator, said oscillator having an output comprised of pulses having a fixed pulse repetition rate, said pulses being applied to said preset divider, said second time period being equal to the time required to fill said preset divider.

7. In combination with a gas turbine engine having an air compressor delivering compressed air from its outlet to a combustor supplied with fuel through a fuel line, and a turbine driven by the gases delivered at its inlet from the outlet of said combustor, means for determining the inlet temperature of said turbine, said means comprising:

- means for generating a first signal comprised of first pulses having a pulse repetition rate proportional to the rate of flow of fuel through said fuel line;
- means for generating a second signal comprised of second pulses having a pulse repetition rate which is a function of the magnitude of the airflow from said compressor;
- means for generating a third signal comprised of third pulses having a repetition rate proportional to the temperature in said compressor outlet;
- means during a variable first time period inversely proportional to the repetition rate of said second pulses for counting the number of said first pulses generated during said first time period;
- means during a fixed second time period for counting the number of said third pulses generated during said second time period; and
- means for summing the numbers of said first and third pulses counted during said time periods and for displaying the summation thereof.

8. The invention as defined in claim 7 wherein said variable first time period is established by means of a preset divider, said second pulses being applied to said divider, said first time period being equal to the time required to fill said preset divider.

9. The invention as defined in claim 8 wherein said fixed second time period is established by means of a clock oscillator, said oscillator having an output comprised of pulses having a fixed pulse repetition rate, said pulses being applied to said preset divider, said second time period being equal to the time required to fill said preset divider.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,789,665 Dated February 5, 1974

Inventor(s) Rudolph Hohenberg

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 2, lines 44 and 45, should read --- proportional to difference pressure) is applied to a preset divider 84. ---.

Column 5, line 39 "bellmount" should read --- bellmouth ---.

Signed and sealed this 21st day of May 1974.

(SEAL)
Attest:

EDWARD M. FLETCHER, JR.
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents