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(54) Assessing lifetime of duct by measuring fluid pressure and temperature within the duct

(57) Sensors in the duct sense the pressure and temperature of the fluid at several points along the duct. The sensors emit voltages which are multiplexed and converted to pulse frequencies at 1. The pulses are counted over a fixed time to determine a value for the pressure and temperature in a microcomputer 1 which is programmed to calculate hoop stress σ from the pressure values and σ is used to determine the relevant value of the Larson Miller parameter P from values thereof stored as a calibration curve against σ . The computer then calculates the overall lifetime tr from the equation:—

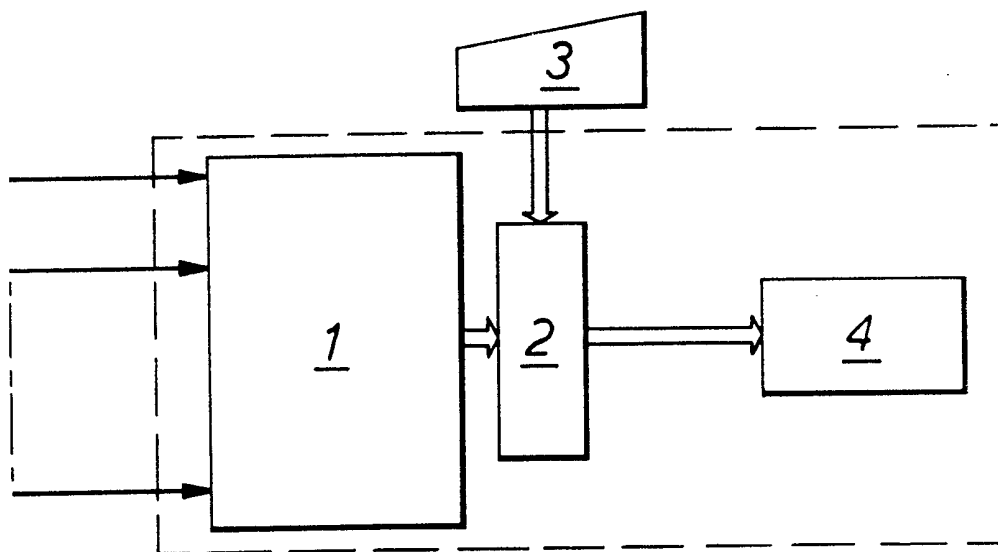
$$tr = 10 \frac{P}{T} - C$$

where T is the temperature in $^{\circ}A$ and C is a constant. C can be taken as being equal to 20 and the life fraction $tF(m)$ of the duct used up between sequential signal samples of the same temperature sensor is determined by the computer from the equation:—

$$tF(m) = \frac{t1 - t2}{tr1}$$

where $t1$ is the time of the last or current sample, $t2$ is the time of the last but one sample, and $tr1$ is that value of tr derived from the current temperature signal. The computer 1 integrates $tF(m)$ to determine the overall fraction $\Sigma tF(m)$ of the life of the duct used upon in the period when the duct has been carrying fluid. Failure of the duct is indicated when $\Sigma tF(m) = 1$.

FIG. 1.



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FIG. 1.

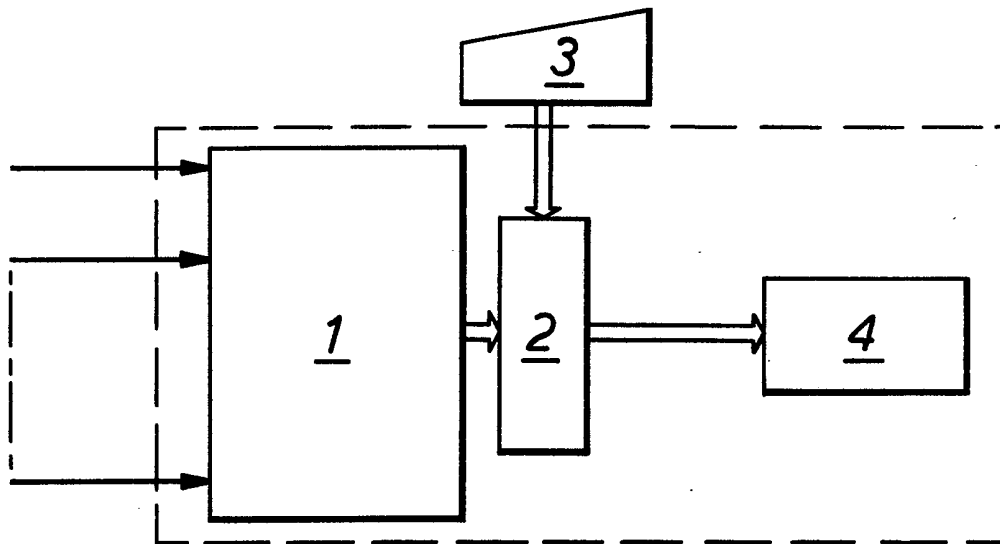
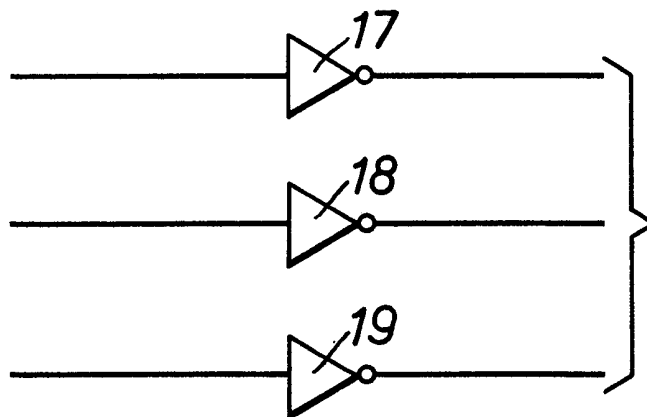
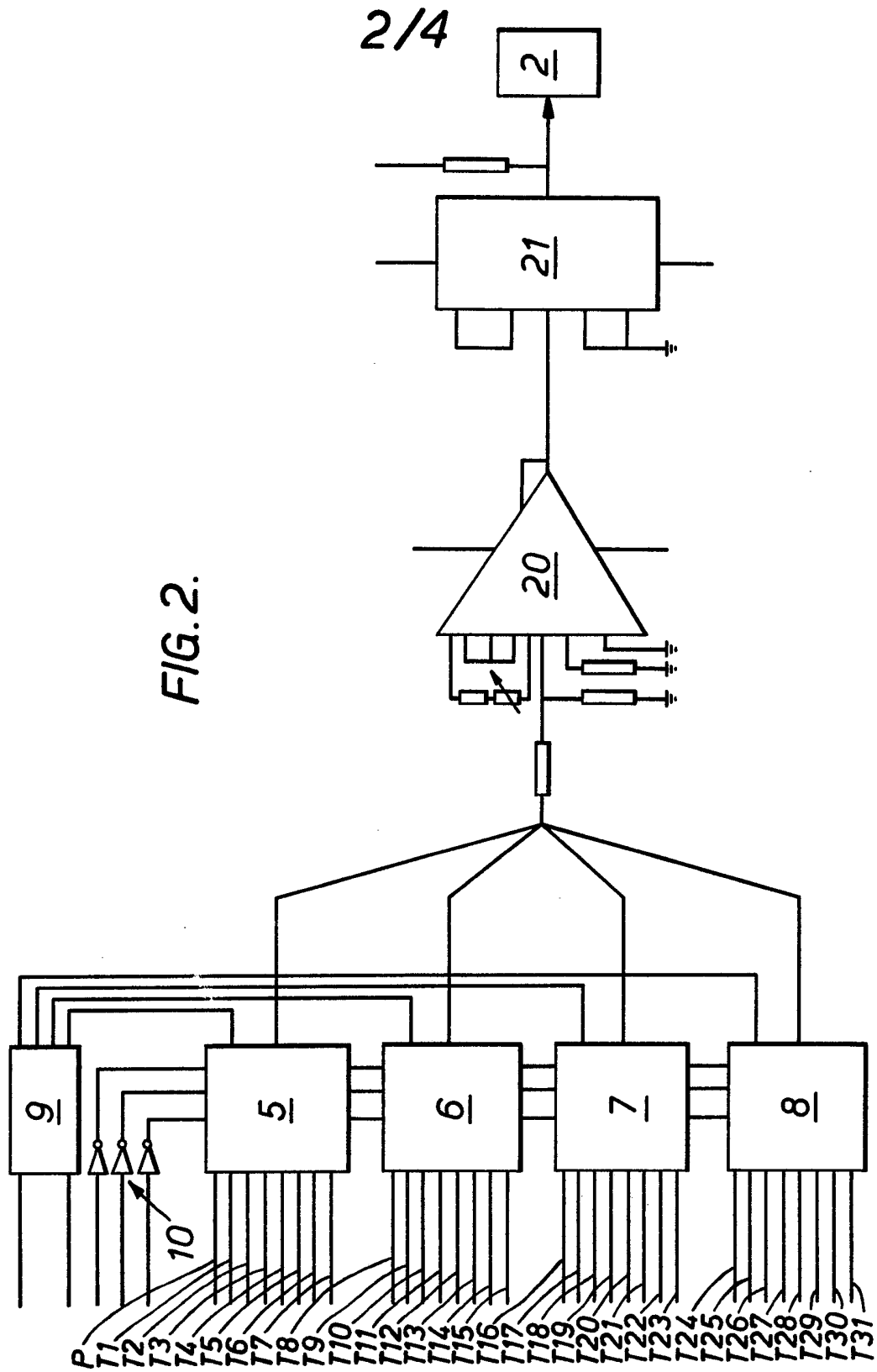


FIG. 4.





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FIG. 3a.

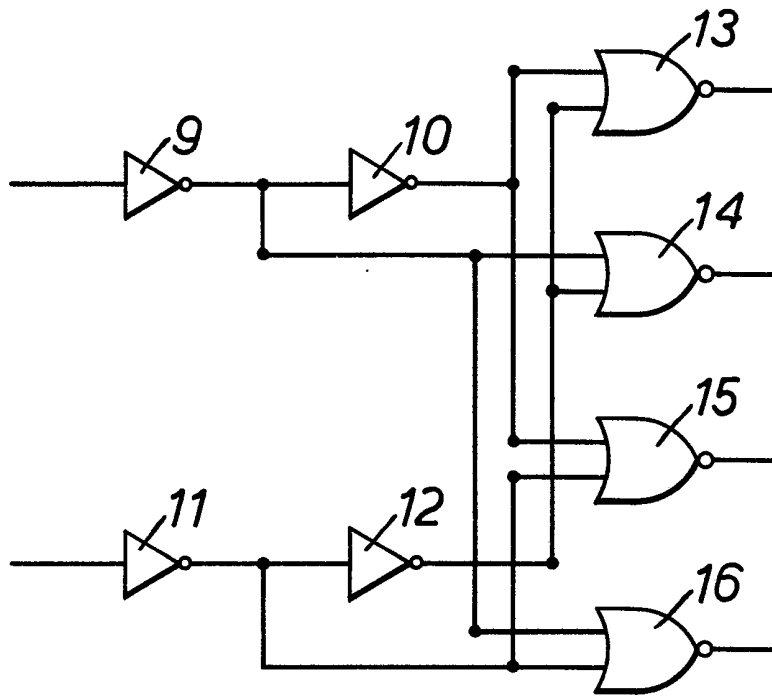
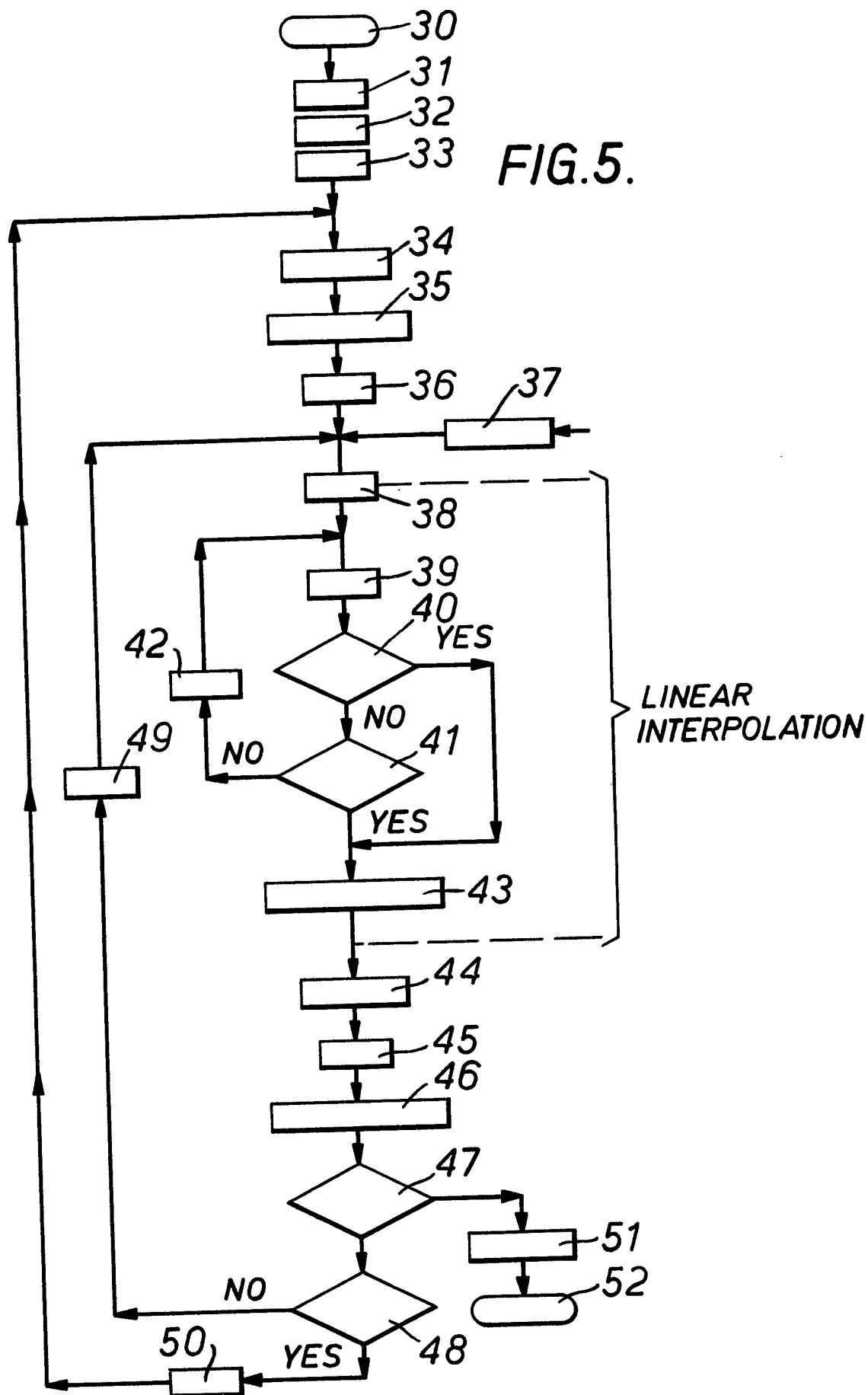


FIG. 3b.

A	B	1	2	3	4
H	H	H	L	L	L
L	H	L	H	L	L
H	L	L	L	H	L
L	L	L	L	L	H

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SPECIFICATION

Assessment of life of duct

The present invention relates to the assessment of the overall lifetime until failure of a duct, particularly a pipe carrying a fluid such as a gas at elevated pressures and temperatures.

According to one aspect of the present invention there is provided a method for assessing the overall lifetime t_r until failure of a duct carrying fluid at elevated temperatures and pressures, the method comprising sensing the pressure and temperature of the fluid at selected points in the duct, emitting signals representative of the pressure and temperature, determining the values of pressure and temperature represented by the signals and deriving the value of t_r from the values of pressure and temperature.

Preferably the temperature of the fluid is sensed at a plurality of points in the duct, a temperature signal is derived for each point and a value of t_r is derived for each signal.

Suitably the signals are continuously sampled sequentially and the value of t_r is derived for each sampled pressure and temperature signal.

Conveniently each emitted signal is an analogue signal and is converted to a digital signal to enable the value of pressure or temperature to be determined.

Preferably the analogue signal is a voltage which is converted to pulses of a frequency analogous to the voltage.

Suitably the pulses are counted during the signal sampling period to provide values of the pressure or temperature.

In one embodiment of the invention, the fraction of life $tF(m)$ of the duct used up between sequential signal samples of the same temperature sensor is determined from the equation

$$tF(m) = \frac{t_1 - t_2}{tr_1}$$

Where t_1 is the time of the last or current signal sample, t_2 is the time of the last but one sample, tr_1 is that value of t_r derived from the current temperature signal and $tF(m)$ is integrated to provide an overall fraction $\Sigma tF(m)$ of the life of the duct which has been used up in the period during which the duct has been carrying fluid.

In this case failure of the duct is indicated when $\Sigma tF(m) = 1$.

In another embodiment of the invention the period during which the duct has been carrying fluid is subtracted from the currently derived value of t_r so as to provide an indication of the period of the remaining useful life of the duct. In this case the highest currently derived value of t_r is taken as the datum. Preferably, however a factor is added to the value of pressure before t_r is determined to provide a margin for safety in the currently derived value of t_r . Suitably the factor is

10% of the value of pressure.
Conveniently the value of the stress to which

the duct is being subjected is derived from the pressure value and is utilised together with the temperature value to derive the value of t_r .

The duct may be a pipe and the derived stress in this case is desirably the hoop stress.

In a preferred embodiment of the invention the relevant value of the Larson Miller parameter (P) as herein defined is selected from a calibration curve of hoop stress against P for the pipe being tested and the value of t_r is derived from the equation:—

$$tr = 10 \left(\frac{P}{T} - C \right)$$

where C is a constant and T is the current temperature value in °A.

Suitably the value of t_r is printed out and/or displayed.

According to another aspect of the present invention there is provided apparatus for assessing the overall lifetime t_r until failure of a duct carrying fluid at elevated pressures and temperatures, the apparatus comprising sensors for sensing the pressure and temperature of the fluid at selected points in the duct and for emitting signals representative of the pressure and temperature and means responsive to the signals for determining the values of the pressure and temperature from the signals and for deriving the value of t_r from the values of the pressure and temperature.

Preferably the sensors sense the temperature of the fluid at a plurality of points in the duct and emit a signal for each point, the signal responsive means being adapted to derive a value of t_r for each signal.

Suitably means are provided to continuously sample the signals sequentially and the signal responsive means is adapted to derive a value for t_r for the sample pressure and temperature signal.

Conveniently the sampling means is a multiplexer.

Preferably each sensor is adapted to emit an analogue signal and means are provided to convert the analogue signal to a digital signal for processing by the signal responsive means.

Suitably the analogue signal is a voltage and the converter means is adapted to convert the analogue signal to pulses of a frequency analogous to the voltage.

Conveniently the signal responsive means includes a counter for counting the pulses during the signal sampling period to provide values of the pressure or temperature.

In one embodiment of the invention, the signal responsive means is adapted to determine the fraction of life $tF(m)$ of the duct used up between sequential signal samples of the same temperature sensor using the equation

$$tF(m) = \frac{t_1 - t_2}{tr_1}$$

where t_1 is the time of the last or current sample, t_2 is the time of the last but one sample, tr_1 is that value of tr derived from the current temperature signal, the signal responsive means being adapted to integrate $tF(m)$ to determine the overall fraction $tF(m)$ of the life of the duct which has been used up in the period during which the duct has been carrying fluid. In this case the signal responsive means is adapted to indicate failure of the duct when $tF(m)=1$.

Preferably the signal responsive means is adapted to derive the value of the stress to which the duct is being subjected from the pressure value and to derive the value for tr from the derived stress value and the temperature value.

The duct itself may be a pipe and in this case the derived stress is the hoop stress.

In a preferred embodiment of the invention means are provided to store a calibration of hoop stress against the Larson Miller parameter (P) as herein defined for the pipe being tested and the signal responsive means is adapted to select the relevant value of P corresponding to the derived hoop stress and to derive the value of tr from the equation:—

$$tr=10\left(\frac{P}{T}-C\right)$$

where C is a constant and T is the current temperature value in °A.

In one embodiment of the invention means responsive to the signal responsive means are provided to print out the value of tr and in another embodiment means may be provided to display the value of tr .

Preferably the signal responsive means and the store means comprise a computer.

Before the actual components of the apparatus are described in detail, it will be believed helpful to explain the steps required to calculate the time to failure tr of a pipe carrying fluid at elevated temperatures and pressures.

The time to failure tr of a material, usually by rupture, at a constant stress is given by the equation:—

$$tr=10\left(\frac{P}{T}-C\right) \quad (1)$$

where tr is the time to failure in hours measured from the instant when the material was first subjected to the stress, P and C are constants and T is the temperature in °A at which the material is being held while being subjected to the stress.

P is the so called "Larson Miller parameter" and from equation (1):—

$$P=T(\log tr + C) \quad (2)$$

If for any given material, the stress required for rupture is plotted as a function of P, all the points are found to fall on a curve, the so called Larson Miller curve.

This relationship was first established by F. R.

Larson and James Miller who revealed their findings for a number of steel alloys in July 1952 in a paper published in the American Society of Mechanical Engineers. That paper contains a full explanation of the theories underlying the authors findings. The authors also empirically discovered that constant C is equal to 20 for certain materials.

The applicants have discovered that the Larson Miller curve can be used to determine tr for a pipe carrying a fluid at elevated pressures and temperatures. To do this it is necessary first to establish a standard Larson-Miller curve for the particular material from which the pipe is constructed by plotting the stress to rupture obtained experimentally against the corresponding parameter P. Once this curve has been established, the stress to which the pipe is being subjected in service can be determined and the parameter P corresponding to this stress can be read off from the curve and tr can be calculated from equation (1) above by inserting the relevant values of T and C.

For a pipe the relevant stress is the hoop stress σ , which can be determined from the equation:—

$$\sigma=\frac{pD}{2t} \quad (3)$$

where p is the pressure of the fluid carried by the pipe in psi, D is the external diameter of the pipe in inches and t is the wall thickness of the pipe in inches.

Thus the time to rupture tr can be calculated by measuring the pressure and temperature of the fluid carried by the pipe in service, the time tr being the total time starting from the instant when the pipe first began to carry fluid.

While the pressure at any point in a fluid is constant, its temperature may vary so that in a length of pipe the temperature of the fluid may be very different at different points along the pipe length. Since the parameter P is directly dependent upon temperature, it will vary along the length of the pipe and thus the time tr will be different for different points in the pipe. It is therefore important for the temperature to be measured at as many points as possible along the pipe length to enable that point at which the rupture time is the shortest to be established.

Consequently the applicants measure temperature at a multiplicity of points along the pipe to provide an accurate overall indication of the rupture time tr .

Each calculated value of tr for each temperature sensor point is then used to calculate the fraction of life $tF(m)$ of the pipe used up between sequential signal samples of the same temperature sensor from the equation:—

$$tF(m)=\frac{t_1-t_2}{tr_1} \quad (4)$$

where t_1 is the time of the last or current signal sample, t_2 is the time of the last but one sample, and tr_1 is that value of tr derived from the current temperature signal.

5 $tF(m)$ is integrated to provide an overall fraction $\Sigma tF(m)$ of the life of the pipe which has been used up in the period during which the duct has been carrying fluid. In this case of course failure of the pipe is predicted when $\Sigma tF(m)$ is equal to one.

10 As an alternative to calculating $tF(m)$, a direct indication of the remaining useful life of the pipe can be obtained by subtracting the period during which the pipe has been carrying fluid from tr_1 .
15 The disadvantage with this method is that the value of tr_1 will only be reliable if the fluid has been at a relatively constant pressure and temperature during the period it has been carried by the pipe. However, if this method is used the point at which the highest currently derived value of tr has been calculated should be taken as the datum since this is the point at which the pipe will first rupture. To provide a margin for safety a factor is added to the value of pressure (or to the calculated stress) before tr_1 is determined and the applicants have found that a factor of 10% of the measured pressure is an adequate margin.

20 An embodiment of the present invention will now be described with reference to the accompanying drawings in which:—

30 Figure 1 is a schematic block circuit diagram of the apparatus

Figure 2 is a more detailed circuit diagram of a number of the components shown in the dotted box in Figure 1,

35 Figure 3a is a circuit diagram of the 2 to 4 line decoder shown schematically in Figure 2,

Figure 3b is a logic table for the decoder,

40 Figure 4 is a diagram of the signal selector shown in Figure 2 and,

Figure 5 is a flow sheet of the sequential operations performed by a microcomputer in assessing tr until failure.

Referring to the drawings, block 1 includes a multiplexer, amplifier and voltage to frequency converter which supply in sequence a series of amplified frequency signals analogous to voltage signals supplied to the multiplexer by a number of sensors. The frequency signals are received by and processed in the central processing unit of a microcomputer 2 together with data in the microcomputer store so as to provide inter alia information on the overall lifetime until failure tr of a duct carrying fluid at elevated temperatures and pressures. The data is supplied to the microcomputer 2 by way of a data teletype 3 and information is output to a printer 4.

Referring to Figure 2 the multiplexer comprises four analogue multiplexer chips 5 to 8 each of which is supplied with analogue voltage signals from eight sensors.

65 Chip 5 is connected to one pressure sensor P and to seven temperature sensors T1 to T7. Chips 6 to 8 however are each connected to eight temperature sensors T8 to T15, T16 to T23 and

T24 to T31 respectively. Where the duct is a pipe or pipe-work, the pressure sensor may be located at any convenient position in the pipe and the temperature sensors at conveniently spaced intervals along the pipe so as to record the temperature at a multiplicity of points along the pipe.

70 The multiplexer 1 also comprises a 2 to 4 line decoder 9 and a signal selector 10 which together form parallel input-output ports to select one of the 32 signal inputs to the multiplexer chips 5 to 8. The 2 to 4 line decoder 9 receives two input control signals which are decoded to give four "enable" signals to select one of the four multiplexer chips 5 to 8. The signal selector 10 receives three input control signals which are supplied in parallel as three input select signals to the each of the four chips so as to select one of the eight sensor signals in that chip selected by the decoder 9.

Referring to Figure 3a, the decoder comprises two pairs of serially connected inverters 9 to 12 and four 'NOR' gates 13 to 16 which each in turn produce a high output in dependence on the level of the two control input signals to the inverters as shown in the table in Figure 3b. As shown in Figure 4 the signal selector comprises three parallel inverters 17 to 19 which respond to the eight combinations of input signals to produce eight combinations of inverted output signals.

Referring again to Figure 2, the decoder 9 enables each chip to be sampled or monitored for 4 seconds and the signal selector samples or monitors each sensor for 0.5 second so that 32 multiplexed inputs of 0.5 second duration are monitored giving a cycle time of 16 seconds.

100 The outputs of the multiplexers 5 to 8 are wires O=Red to the input of a low drift instrumentation amplifier 20. The amplifier 20 is connected to the analogue input of a voltage to frequency converter 21. The output of the converter 21 is connected directly to the counter timer circuit channel of the microcomputer 2. This circuit inter alia counts the number of frequency pulses over a fixed time period and hence enable the values of sensed pressure or temperature to be measured.

105 The microcomputer 2 is a Zilog Z80 micro-computer which is programmed to calculate the time tr , the programme residing in 4K bytes of "read only" memory. The microcomputer 2 incorporates a teletype monitor 3 to provide teletype initialisation and a source code contained in several modules as described below.

120 Main module

125 This is the main control routine which calls the other routines. The data areas are initialised on reset (or power up) and the input parameters solicited from the teletype 2. The main programme loop is within this module, supervising the analysis of the data, the synchronisation of the calculations with the input of new readings and the output of results.

Module pressure

From the counter time count, the pressure of fluid in the pipe is calculated and hence the pipe hoop stress σ . The parameter P is calculated from pre-input values of P vs $\log_{10} \sigma$ by linear interpolation.

Module temperature

From the counter time count and the parameter P calculated by the Pressure Module, tr is calculated for each of the 31 temperature sensors. The value of tr may be used either to calculate the fraction of life $tF(m)$ which is integrated as previously described to provide an integral $\Sigma tF(m)$ or the remaining useful life of the pipe may be directly calculated from tr . In this case tr may be calculated with the value of P or σ modified by the addition of a factor for safety.

Module results

The results are converted to a standard code and output to the printer 3 shown in Figure 1.

Module interrupt

The central timer circuit is programmed to interrupt on two channels and both these interrupts are handled by routines in the main module.

(1) Timer interrupt

The timer is interrupted every 25 ms, the clock is incremented and the sensor being monitored at the particular time is read and updated every 0.5 second.

(2) Counter interrupt

The counter is interrupted every 256 pulse counts and the total is incremented and the counter restarted.

Module PROM store

This module contains the permanent data which accurately defines the system and includes the Data Module. The Data Module contains values of $\log_{10} \sigma$ and the corresponding value of P which are input before the fluid is introduced into the pipe.

Referring to Figure 5, the computer operations numbered are as follows:—

- 30) Start—switch on power
- 45 31) Input $M=1$ where M is the temperature sensor to be sampled (normally a thermocouple).
- 32) Read L and N where L =number of thermocouples being sensed and N =number of data points to plot or describe the Larson-Miller curve.
- 50 33) Input $tF(m)$ $m=1, L=0$ where $tF(m)$ is the fraction of life used up between signal samples from the same temperature sensor.
- 34) Dimension $\sigma(N)$; $P(N)$
- 55 35) (i) Input $\sigma(l)$ data where σ_D is the stress data obtained experimentally to construct the Larson-Miller curve and $l=1,2,3, \dots N$.
- (ii) Input $P_D(l)$ data where P_D is the Larson-

Miller parameter corresponding to $\sigma_D(l)$ and $l=1,2,3, \dots N$.

Statement 34) sets aside a storage area to contain the $\sigma_D(l)$ and $P_D(l)$ data.

The $\sigma_D(l)$ and $P_D(l)$ values may be stored permanently if the system is to be dedicated to a particular component material.

- 65 36) $P_d=N$
- 37) Read σ and T (input for multiplexer) for M
- 38) $l=2$
- 39) $J=l$
- 70 40) Is stress $\sigma < \sigma_D(l)$
- 41) Does $l=P_D$
- 42) $l=l+1$.

$$43) P = P_D + \frac{\sigma - \sigma_{D(l-1)}}{\sigma_{D(J)} - \sigma_{D(J-1)}} \times P_{D(J)} - P_{D(J-1)}$$

This equation enables the relevant value of P to be determined by linear interpolation.

$$44) tr = 10 \left(\frac{P}{T} - 20 \right)$$

45) Print/display rupture time tr

$$46) tF(m) = \frac{t1 - t2}{tr}$$

where $t1$ is time of the present temperature measurement and $t2$ is the time of the last but one temperature measurement.

- 80 47) Does $\Sigma tF(m)=1$
- 48) Does $M=L$
- 49) $M=M+1$
- 85 50) $M=1$
- 51) Sound alarm
- 52) Stop.

While not shown, tr in 44) can be calculated from a P value derived from the pressure or stress value to which 10% of that value has been added to provide a margin for safety. The remaining useful life of the pipe can then be calculated by subtracting the period during which the pipe has been carrying the fluid from tr .

It will be appreciated that while not described there are other methods, apart from the Larson-Miller relationship, for deriving the value of tr .

Claims

1. A method for assessing the overall lifetime tr until failure of a duct carrying fluid at elevated pressures and temperatures, the method comprising sensing the pressure and temperature of the fluid at selected points in the duct, emitting signals representative of the pressure and temperature, determining the values of pressure and temperature represented by the signals and deriving the value of tr from the values of pressure and temperature.

2. A method as claimed in Claim 1 in which the

temperature of the fluid is sensed at a plurality of points in the duct, a temperature signal is derived for each point and a value of t_r is derived for each signal.

5 3. A method as claimed in Claim 1 or Claim 2 in which the signals are continuously sampled sequentially and the value of t_r is derived for each sampled pressure and temperature signal.

10 4. A method as claimed in any of Claims 1 to 3 in which each emitted signal is an analogue signal and is converted to a digital signal to enable the value of pressure or temperature to be determined.

15 5. A method as claimed in Claim 4 in which the analogue signal is a voltage which is converted to pulses of a frequency analogous to the voltage.

20 6. A method as claimed in Claim 5 in which the pulses are counted during the signal sampling period to provide values of the pressure or temperature.

25 7. A method as claimed in any of the preceding claims in which the fraction of life $tF(m)$ of the duct used up between sequential signal samples of the same temperature sensor is determined from the equation

$$tF(m) = \frac{t_1 - t_2}{t_{r_1}}$$

30 Where t_1 is the time of the last or current signal sample, t_2 is the time of the last but one sample, t_{r_1} is that value of t_r derived from the current temperature signal and $tF(m)$ is integrated to provide an overall fraction $\Sigma tF(m)$ of the life of the duct which has been used up in the period during which the duct has been carrying fluid.

35 8. A method as claimed in Claim 7 in which failure of the duct is indicated when $\Sigma tF(m) = 1$.

40 9. A method as claimed in any of Claims 1 to 6 in which the period during which the duct has been carrying fluid is subtracted from the currently derived value of t_r so as to provide an indication of the period of the remaining useful life of the duct.

45 10. A method as claimed in Claim 9 in which the highest currently derived value of t_r is taken as the datum.

50 11. A method as claimed in Claim 9 or Claim 10 in which a factor is added to the value of pressure before t_r is determined to provide a margin for safety in the currently derived value of t_r .

55 12. A method as claimed in Claim 11 in which the factor is 10% of the value of pressure.

13. A method as claimed in any of the preceding claims in which the value of the stress to which the duct is being subjected is derived from the pressure value and is utilised together with the temperature value to derive the value of t_r .

60 14. A method as claimed in Claim 13 in which the duct is a pipe and the derived stress is the hoop stress.

15. A method as claimed in Claim 14 in which

the relevant value of the Larson Miller parameter P as herein defined is selected from a calibration curve of hoop stress against the LMP for the pipe being tested and the value of t_r is derived from the equation:—

$$t_r = 10 \left(\frac{P}{T} - C \right)$$

Where C is a constant and T is the current temperature value in $^{\circ}A$.

70 16. A method as claimed in any of the preceding claims in which the value of t_r is printed out and/or displayed.

75 17. Apparatus for assessing the overall lifetime t_r until failure of a duct carrying fluid at elevated pressures and temperatures, the apparatus comprising sensors for sensing the pressure and temperature of the fluid at selected points in the duct and for emitting signals representative of the pressure and temperature and means responsive to the signals for determining the values of the pressure and temperature from the signals and for deriving the value of t_r from the values of the pressure and temperature.

80 18. Apparatus as claimed in Claim 17 in which the sensors sense the temperature of the fluid at a plurality of points in the duct and emit a signal for each point, the signal responsive means being adapted to derive a value of t_r for each signal.

85 19. Apparatus as claimed in Claim 17 or Claim 18 in which means are provided to continuously sample the signals sequentially and the signal responsive means is adapted to derive a value for t_r for the sampled pressure and temperature signal.

90 20. Apparatus as claimed in Claim 19 in which the sampling means is a multiplexer.

21. Apparatus as claimed in any of Claims 17 to 20 in which each sensor is adapted to emit an analogue signal and means are provided to convert the analogue signal to a digital signal for processing by the signal responsive means.

22. Apparatus as claimed in Claim 21 in which the analogue signal is a voltage and the converter means is adapted to convert the analogue voltage to pulses of a frequency analogous to the voltage.

23. Apparatus as claimed in Claim 22 in which the signal responsive means includes a counter for counting the pulses during the signal sampling period to provide values of the pressure or temperature.

24. Apparatus as claimed in any of Claim 17 to 23 in which the signal responsive means is adapted to determine the fraction of life $tF(m)$ of the duct used up between sequential signal samples of the same temperature sensor using the equation:—

$$tF(m) = \frac{t_1 - t_2}{t_{r_1}}$$

where t_1 is the time of the last or current sample, t_2 is the time of the last but one sample, t_{r_1} is that

value of t_r derived from the current temperature signal, the signal responsive means being adapted to integrate $tF(m)$ to determine the overall fraction $\Sigma tF(m)$ of the life of the duct which has been used up in the period during which the duct has been carrying fluid.

25. Apparatus as claimed in Claim 24 in which the signal responsive means is adapted to indicate failure of the duct when $\Sigma tF(m)=1$.

26. Apparatus as claimed in any of Claims 17 to 25 in which the signal responsive means is adapted to derive the value of the stress to which the duct is being subjected from the pressure value and to derive the value for t_r from the derived stress value and the temperature value.

27. Apparatus as claimed in Claim 26 in which the duct is a pipe and the derived stress is the hoop stress.

28. Apparatus as claimed in Claim 27 in which means are provided to store a calibration of hoop stress against the Larson Miller parameter (P) as herein defined for the pipe being tested and the signal responsive means is adapted to select the relevant value of P corresponding to the derived

hoop stress and to derive the value of t_r from the equation:—

$$t_r = 10 \left(\frac{P}{T} - C \right)$$

where C is a constant and where T is the current temperature value in °A.

29. Apparatus as claimed in any of Claims 17 to 28 in which means responsive to the signal responsive means are provided to print out the value of t_r .

30. Apparatus as claimed in any of claims 17 to 29 in which means responsive to the signal responsive means are provided to display the value of t_r .

31. Apparatus as claimed in any of claims 28 to 30 in which the signal responsive means and the store means comprise a computer.

32. A method substantially as hereinbefore described with reference to the accompanying drawings.

33. Apparatus substantially as hereinbefore described with reference to the accompanying drawings.