

PROTECTION FOR HYDRAULIC MACHINES

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This invention relates to protection for hydraulic machines, that is to say protection for pumps, motors, turbines and the like.

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Protection is to be understood to mean a safeguard for the hydraulic machine so that it may function according to its design performance limits and not move outside of said limits into malfunction without giving a warning to an engineer in charge of its operation.

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It has been known since c.1914 that the efficiency of a hydraulic machine may be estimated by a determination of the small differences in the fluid temperature between the inlet and the outlet of the machine in relation to the fluid head between said inlet and said outlet.

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This is generally expressed mathematically in the convenient form enunciated by:-

WILLM. G. and CAMPMAS.P. in an article entitled

Efficiency measurements for hydraulic turbines by
the Poirson Thermometric method translated into
English in Supplement No.6/1956 from La Houille
Blanche 9 (1954) p449/550, and from BARBILLION.L.
5 Méthode thermométrique de mesure du rendement
des turbines hydrauliques Revue Generale
del'électricité 26 (1929) p487-497.

The theory of the thermometric or thermodynamic
method is as follows:-

10 Efficiency in a hydraulic pump for example
may be expressed as

$$\frac{\text{Work Done or } W_o}{\text{Effort } W_1}$$

but $W_1 = W_o + \text{Losses}$.

15 $\eta_p = \frac{1}{1 + \frac{\text{Losses}}{W_o}}$ where η_p is the pump efficiency

thus providing one can determine the term $\frac{\text{Losses}}{W_o}$,

20 η_p may be calculated.

Some of the energy that is lost in pumping may go
to drain through gland water or bearing cooling water
but the majority of it is dissipated as heat in the
pumped fluid.

25 The energy dissipated as heat is defined as

$$C_p Q \Delta T$$

where C_p is the Specific heat of the Fluid

Q is the Flow

ΔT is the Temperature rise across the pump

5 Hence Losses = $C_p Q \Delta T$ where H is the total

W_o gQH generated head in metres.

Therefore:- $\eta_p = \frac{1}{1 + \frac{C_p Q \Delta T}{gQH}}$

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an expression that is totally independent of flow,
taking C_p as 4186

and g as 9.81 we have $\eta_p = \frac{1}{1 + 426.7 \frac{\Delta T}{H}}$

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The above equation is simplified as it assumes
constant thermodynamic properties for the pumped
fluid. The full equation is given by Foord.T.R. et
al. Thermometric Method of Measuring Hydraulic
Efficiency Water Power. Oct (1964) p432-434.

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$$\eta_p = \frac{V_o (P_2 - P_1) (1 - \beta) + \frac{1}{2} g (V_2^2 - V_1^2) + (Z_2 - Z_1)}{V_o (P_2 - P_1) (1 - \alpha) + j C_p (t_2 - t_1) + \frac{1}{2} g (V_2^2 - V_1^2) + (Z_2 - Z_1)}$$

$$V_o (P_2 - P_1) (1 - \alpha) + j C_p (t_2 - t_1) + \frac{1}{2} g (V_2^2 - V_1^2) + (Z_2 - Z_1)$$

Where P is pressure; t temperature; V velocity;

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5 Z pressure-gauge height; C_p specific heat of water at constant pressure; V_0 the specific volume of water at 4°C , 760mm Hg; J the mechanical equivalent of heat. The suffixes 1 and 2 refer to the inlet and outlet respectively. α and β are thermodynamic factors based on the chosen value for V_0 and are obtained from published charts. The value of α for water is zero at 4°C rising to about 0.044 at 15°C . In practice, β is usually small and can be neglected.

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Under the following conditions the above equation (1) may be simplified whilst still retaining a high degree of accuracy.

Conditions

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$$P_2 - P_1 \gg \frac{1}{2} \rho (V_2^2 - V_1^2) + (Z_2 - Z_1) \rho g$$

$$10^\circ\text{C} < t_2 < 50^\circ\text{C}$$

Formula (1) becomes

$$\frac{W}{P} = \frac{1}{1.0189 - 0.0041t_2 + 426.7 \frac{\Delta T}{H}} \quad (2)$$

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If we consider a pump in which:

Q the flow is $400\text{m}^3/\text{hr}$

Head is 100m

Efficiency η_P is 80%

Temperature of fluid is 11°C

5 Then from equation (2) above the temperature rise across the pump, ΔT is 0.065°C that is 65 millidegrees Celsius.

It is unnecessary with this estimation of efficiency to know the flow characteristics of the machine.

10 According to the invention there is provided a hydraulic machine protection method comprising;

selecting an unacceptable deviation in efficiency from an ideal efficiency for the hydraulic machine;

15 evaluating a protection value for the selected unacceptable efficiency, wherein the protection value comprises the temperature difference ΔT across a fluid inlet and fluid outlet of the hydraulic machine, ΔT being evaluated according to a predetermined
20 formula;

monitoring said input and output temperatures of the hydraulic machine and developing an alarm signal in response to the protection value falling outside a range extending between the protection value for the
25 ideal efficiency and the protection value for the

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unacceptable efficiency. In one embodiment of the invention the temperature difference T is evaluated according to the formula

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$$\eta_p = \frac{1.0189 - 0.0041t_2 + 426 \Delta T}{H}$$

H

where η_p is the efficiency, H is the head in metres and t_2 the output temperature of the fluid t are known.

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According to another aspect of the invention there is provided a hydraulic machine protection method comprising:

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selecting an unacceptable deviation in efficiency from an ideal efficiency for the hydraulic machine;

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evaluating a protection value for the selected unacceptable efficiency, wherein the protection value comprises the temperature difference ΔT across a fluid inlet and fluid outlet of the hydraulic machine divided by the value of the differential pressure across the hydraulic machine, ΔT being evaluated according to a predetermined formula;

monitoring said input and output temperatures of the hydraulic machine and developing an alarm signal

in response to the protection value falling outside a range extending between the protection value for the ideal efficiency and the protection value for the unacceptable efficiency.

5 Ideally electrical signals from two probes are electrically subtracted and the resultant signal fed into a micro-processor to evaluate the protection value and relate it with the value range. The signal so produced is then deployed as a protection value
10 which, depending upon its value, will show when the hydraulic machine is working within the correct limits of its design. The protection value develops an alarm signal to sound an alarm or switch off the hydraulic machine once that value is above or below safe and
15 correct working conditions for the machine.

 The invention will be more fully understood from the following description given by way of example only with reference to the figures of the accompanying drawings in which:-

20 Figure 1 is a circuit diagram of a differential temperature measurement means for a protection device using two terminal integrated circuit temperature transducer; and

 Figure 2 is a block diagram of a hydraulic

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machine protection device.

Referring now to Figure 1 there is shown:-

5 The two AD590 devices shown are two terminal integrated circuit temperature transducers made by analog devices P.O. Box 280 Norwood Massachusetts 02062 United States of America.

These transducers produce an output current proportional to absolute temperature.

10 For supply voltages between +4V and +30V these devices act as a high impedance, constant current regulator passing 1 microamp/degree celsius.

The circuit of Figure 1 demonstrates one method by which differential temperature measurements can be made.

15 R1 and R2 are used to trim the operational amplifier to take into account any manufacturing tolerance in the AD590 themselves.

The modus operandi of the circuit is as follows.

20 T1 responds to the fluid outlet temperature and T2 responds to the fluid inlet temperature of the machine.

25 The configuration of T1 and T2 shown produces a small current which is a combination of the absolute temperature difference between T1 and T2 and the unavoidable manufacturing tolerances between AD590

(18)

- 8 -

(T1) and AD590 (T2).

The manufacturing tolerance is corrected by means of R1 and R2.

5 The resulting current signal is then converted into a voltage signal by way of the operational amplifier AD741.

The device of Figure 2 may be employed in the measurement of relative performance of hydraulic machines and related to their overall protection.

10 Consider the example of a pump as referred to above which is pumping water not at 11°C but at 4°C , then it generates at a hydraulic head of 100 metres and an efficiency of 80% a temperature rise of 0.058°C .

15 If a malfunction in this pump is such that the pump now generates a hydraulic head of 200 metres at an efficiency of 40% then the temperature rise will be 0.703°C .

20 Thus whilst the head has increased by a factor of two and the efficiency has halved the differential temperature has increased by a factor of 12.5.

This amplification effect of the change in running conditions is the basic principle of the pump protection unit.

25 Such a system may contain a cost penalty

feature by the inclusion of pressure signals into the temperature differential and specific heat equation.

The accuracy of the protection device may be improved by incorporating a pressure signal into the device.

For example again using the previous formulae with the following pumping conditions.

Generated head 100M efficiency 80% water temperature 4 degrees differential temperature 0.058°C.

If the conditions now change such that the head generated is only 50 metres but the differential temperature is unchanged then the efficiency of the pump is 67%.

In this instance a change in pumping conditions has not produced a change in differential temperature measurement.

If, however, we now incorporate the differential pressure signal into the equation such that the differential temperature signal is divided by the differential pressure signal then the following result is achieved.

Case 1

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- 10 -

Differential Temperature = 58

Differential Pressure 100 = 0.58

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Case 2

Differential Temperature 58

Differential Pressure 50 = 1.16

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This change in signal is sufficient to operate the control systems.

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CLAIMS

1. A hydraulic machine protection method comprising:-

5 selecting an unacceptable deviation in efficiency from an ideal efficiency for the hydraulic machine;

10 evaluating a protection value for the selected unacceptable efficiency, wherein the protection value comprises the temperature difference ΔT across a fluid inlet and fluid outlet of the hydraulic machine, ΔT being evaluated according to a predetermined formula;

15 monitoring said input and output temperatures of the hydraulic machine and developing an alarm signal in response to the protection value falling outside a range extending between the protection value for the ideal efficiency and the protection value for the unacceptable efficiency.

20 2. A hydraulic machine protection method comprising:

selecting an unacceptable deviation in efficiency from an ideal efficiency for the hydraulic machine;

evaluating a protection value for the selected



unacceptable efficiency, wherein the protection value comprises the temperature difference ΔT across a fluid inlet and fluid outlet of the hydraulic machine divided by the value of the differential pressure across the hydraulic machine, ΔT being evaluated according to a predetermined formula;

monitoring said input and output temperatures of the hydraulic machine and developing an alarm signal in response to the protection value falling outside a range extending between the protection value for the ideal efficiency and the protection value for the unacceptable efficiency.

3. A method as claimed in Claim 1 or 2 wherein said value of ΔT is evaluated according to the formula

$$\eta_P = \frac{1.0189 - 0.0041t_2 + 426.7\Delta T}{H}$$

where η_P is the efficiency, H is the head in metres and t_2 is the output temperature.



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- 13 -

4. A hydraulic machine protection method substantially is herein described with reference to the accompanying drawings.

5. Apparatus for carrying out the method of any preceding claims, said apparatus being constructed and arranged substantially as herein described with reference to the accompanying drawings.

