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Adjustment and Description, of the Electronically Controlled VIT

The purpose of this description is to give a thorough explanation of the electronically controlled VIT (Variable Injection Timing) system. The control function as such is implemented in the electronic governor, which gives an output to an I/P-converter. The I/P-converter generates a pneumatic control signal for the VIT-actuators, which is similar to the signal produced by the mechanical VIT-control device.

The electronic control is only active when running ahead during engine room control and bridge control. For astern and emergency running, the manoeuvring system takes over the control and transmits a preadjusted pressure to the VIT-actuators.

The purpose of the electronically controlled VIT is the same as for the mechanical VIT system, i.e. to keep the p_{max} constant above the breakpoint and thus save fuel. In addition, the electronic VIT has the advantage of compensating for variations in the scavenge air pressure, for which reason readjustments on account of changes in the ambient conditions are unnecessary. Furthermore, adjustments during operation are much easier, as this can be done just by entering correction values into the governor.

An essential difference between the mechanical VIT and the electronic VIT is the use of the breakpoint and how pressure rise is controlled:

For the mechanical VIT, the pressure rise is controlled in a fixed relation to the engine's load (fuel pump index) over the whole load range, and there is a fixed breakpoint corresponding to the nominal breakpoint (from performance data).

In the electronic VIT, the pressure rise of Range III is controlled in a fixed relation to the load, and control of Range I is variable dependent on the scavenge air pressure. The result, therefore, is a floating breakpoint, see Fig. 1. With the electronic VIT, the nominal breakpoint is only used in determining the gradient of curve III and when measurements are taken during adjustments.

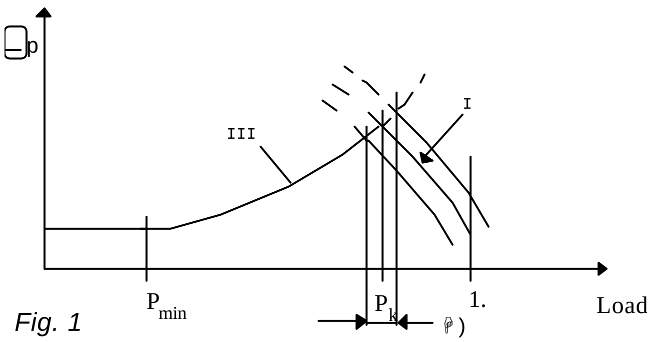


Fig. 1

*) Variation of P_k as a result of Curve I being offset when changing p_{sc}

The following section describes the adjustment procedure to be carried out during testbed running and adjustment during service. The adjustment must be verified during the sea trial.

VIT parameters and variables		
p_{max} :	[bar abs]	Maximum pressure in cylinder
$D\,p_{max,till}$:	[bar]	Maximum allowed pressure rise from p_{comp} to p_{max}
p_{comp} :	[bar abs]	Compression pressure in cylinder
P_k :	[relative unit]	Power at breakpoint
P_{min} :	[relative unit]	Minimum power, curve III
$D\,p_k$:	[bar]	Pressure rise at breakpoint
$D\,p_{MCR}$:	[bar]	Pressure rise at MCR
k_c :	[bar abs/bar abs]	Ratio of p_{comp} relative to p_{sc}
n_r :	[relative unit]	Engine speed
I_r :	[relative unit]	Effective fuel pump index
p_{sc} :	[bar abs]	Scavenge air pressure
p_{offset} :	[bar]	Adjustment of p_{max} level (for fuel quality)
$D\,p_{min}$:	[bar]	Minimum value of pressure rise
k_I :	[mA/bar]	Conversion factor from calculated setpoint Δp to control signal (4-20 mA)
$D\,p_{max,control}$:	[bar]	Maximum allowed control range, to guard against excessive p_{max} in the event of an indication error from the scavenge air transducer
t_1 :	[s]	Change rate of ramp function for increasing output
t_2 :	[s]	Change rate of ramp function for decreasing output

Commissioning parameters:				
		Range		Default
p_{max} :	[bar abs]	100 – 250		*)
$D\ p_{max,till}$:	[bar]	0 – 50		35
k_c :		25 – 50		*)
P_k :	[relative unit]	0.5 – 0.95		*) ~ 0.85
P_{min} :	[relative unit]	0 – 0.6		0.2
$D\ p_k$:	[bar]	10 – 50		*)
$D\ p_{MCR}$:	[bar]	0 – 25		*)
$D\ p_{min}$:	[bar]	-50 – 50		$= D\ p_{MCR}$
k_I :	[mA/bar]	0 – 2		0.35
$D\ p_{max,control}$:	[bar]	0 – 20		10
p_{offset} :	[bar]	-50 – 50		0
t_1 :	[s]	0 – 120		30
t_2 :	[s]	0 – 120		1

*) *Engine dependent values derived from the calculated performance data. The values may have to be adjusted in accordance with the actual testbed data.*

Service parameters:

p_{offset} : [bar] (adjustment for fuel quality)
Cancellation of VIT function ⇒ 4 mA out.

Internal parameters from governor:

n_r [relative]
I_r [relative]
p_{sc} [bar abs]

Please note:
All formulas refer to absolute pressure. If only gauge pressure is available, the absolute pressure can be calculated as:

$$p\ [bar\ abs] = p\ [bar\ gauge] + 1$$

Adjustments during commissioning at testbed

Adjustments are made only in the high load range; in the breakpoint and at MCR. Adjustments below the breakpoint (Ranges III and IV) are not normally necessary, because in this situation the pressure rise is the subject of fixed control, and Δp_{min} just represents a point for defining the lead.

1. Check that the VIT-actuators move satisfactorily and that the electronics and mechanics comply.

   Check/adjust the I/P-converter so that a 4 mA signal gives a control air pressure of 0.5 bar (minimum VIT-index), and 20 mA gives 5.0 bar (maximum VIT-index).

2. Check that the default parameters are entered and are realistic for the actual engine. Parameters marked *) are taken from the calculated performance data of the actual engine, and these are corrected if needed in accordance with the actual testbed results.

   k_l normally need not be changed. If necessary, use empirical values from corresponding engines.

   If it is the first time electronically controlled VIT is going to be used on the engine in question, k_l can be found as follows:

   A. Run the engine up to the breakpoint

   B. Take indicator diagrams at 0 VIT index and at a VIT index as high as possible, without exceeding max. Δp and p_{max}.

      The VIT index can be manually controlled by means of p_{offset}.

   C. Determine the change in Δp for the observed change in VIT index.
      Example: at 0 VIT index Δp = 10 bar
      at 8 VIT index Δp = 34 bar.

      1 VIT index is equal to a pressure rise of $\frac{(34-10)}{8} = 3$ bar

      If max VIT index is 14 then the maximum possible pressure rise variation is equal to 14 x 3 = 42 bar, (0-14) VIT index is equal to (20-4) = 16 mA.
      $k_l = \frac{16}{42} = 0.381$ mA/bar.

3. Run the engine up to a load just above the breakpoint and then:

4. Take indicator diagrams and, from these diagrams, determine p_{comp} and p_{max}.

5. Check k_c. The governor shows the calculated value for p_{comp} (= $k_c \times p_{sc}$). If this deviates from the measured p_{comp}, correct k_c.

6. Check and, if necessary, adjust the value in the governor for the pressure rise at the breakpoint Δp_k.

7. Adjust p_{max} by entering the value of p_{offset} in the governor by the amount in bar by which it is desired to change p_{max}. Note $p_{offset,\ breakpoint}$ for later use.

8. Take indicator diagrams and note $\Delta p_{breakpoint} = p_{max} - p_{comp}$ for later use.

9. Increase the engine load to MCR and then:

10. Take indicator diagrams, and determine p_{comp} and Δp_{max}.

11. Adjust p_{offset} by the amount in bar by which it is desired to change p_{max}. Note $p_{offset,MCR}$ for later use.

12. Take indicator diagrams. Note $\Delta p_{MCR} = p_{max} - p_{comp}$ for later use.

13. If p_{offset} is different in the breakpoint and at MCR, correct k_I and p_{offset} according to the following formulae:

$$k_{I\ corr} = k_I \left(1 + \frac{p_{offset,\ MCR} - p_{offset,\ breakpoint}}{\Delta p_{MCR} - \Delta p_{breakpoint}}\right)$$

$$p_{offset,\ corr} = p_{offset,\ MCR} + \left(\frac{k_I}{k_{I,\ corr}} - 1\right) \Delta p_{MCR}$$

i.e. insert the measured values noted in points 7, 8, 11 and 12 in the above formulae. New values for k_I and p_{offset}t must be entered in the governor.

14. If the VIT system is unstable, the change rate of the output signal must be decreased to make the system more 'sluggish':

    t_1, which is the time it takes for the output signal to change from 4 – 20 mA, should be increased, but only so much that the VIT system is just stable.

    t_2, which represents the rate of change for the falling signal (20 – 4 mA), should not be set above the default value.

15. After adjustment, take new indicator diagrams to verify that the adjustment is correct.

    The above applies to a simultaneous adjustment of all cylinder units of the engine. Individual adjustment of each fuel pump, to obtain the same maximum pressure on all cylinders, is done in the same way as for the mechanical VIT system.

Adjustment of manoeuvring system on commissioning

The reducing valve which provides the pneumatic signal to the VIT actuators during astern running, must be adjusted to give a fixed VIT-index corresponding to the VIT-index in the break-point for ahead to ensure a safe start astern and give the best possible astern performance. The pressure (approximately 3-5 bar) which the I/P-converter provides during ahead running under remote control can be used as the setpoint.

The reducing valve, which provides a signal to the VIT-actuators during emergency running ahead, is adjusted to give minimum VIT-index (approximately 0.5 bar). This safeguards the engine as much as possible during emergency running and ensures that the pressure rise does not exceed the permissible value.

After the final adjustment, draw diagrams are to be taken for astern running to ensure that the pressure rise ($p_{max} - p_{comp}$) does not exceed the permissible level.

Adjustments during operation

Changes in the fuel quality or wear of the fuel injection pumps may make it necessary to readjust the VIT-system.

1. Take indicator diagrams in the range just above the breakpoint.

2. Adjust p_{max} by changing the value of p_{offset} in the governor by the same number of bar by which it is desired to change p_{max}.

3. Take new indicator diagrams to check the adjustment.

In the event of poor cylinder condition, it is recommended that the VIT-index is set to minimum. This is done by cancelling the VIT-function in the governor.

The following section describes the control function of the electronically controlled VIT system. This section is intended for information only.

Calculation of pressure rise

For VIT control, the following general expression applies:

$$p_{max} = p_{comp} + \Delta p \qquad \text{, where } \Delta p_{min} \leq \Delta p \leq p_{max}$$

The pressure rise Δp between compression pressure and maximum pressure is determined as a function of the engine's actual load, within the upper and lower limits of the pressure rise (Δp_{max} and Δp_{min}).

The governor calculates the pressure rise for the ranges shown in Fig. 2.

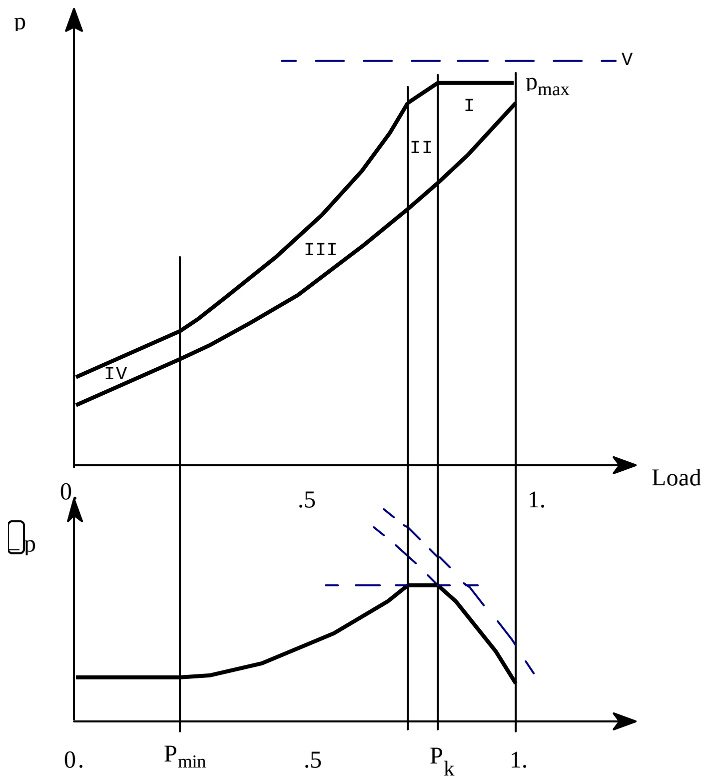


Fig. 2

Range I: The pressure rise is a controlled variable dependent on the scavenge air pressure, and is calculated as follows:

$$\Delta p = p_{max} - p_{comp}$$

As, in practice, the relation between the compression pressure and the scavenge air pressure is approximately constant in the high load range, the constant k_c can be used, thus giving:

$$\Delta p_I = p_{max} - k_c \times p_{sc} \quad , \text{ where } k_c = \frac{p_{comp}}{p_{sc}}$$

k_c is calculated on the basis of the actual values measured in [bar abs] during running at MCR on the testbed. The values measured at the breakpoint can also be used, as k_c is approximately constant in the high load range.

p_{sc} is an internal parameter in the governor (the same as used by the governor for the scavenge air limiter).

The advantage of introducing the constant k_c, and using the scavenge air pressure as a variable, is that compensation is automatically obtained for variation in the scavenge air pressure, caused by ‘ambient conditions’, etc.

Range II:

$$\Delta p_{II} = \Delta p_{max,\ till}$$

In the area around the breakpoint a maximum limit is introduced which functions as a fixed upper limit so that the pressure rise cannot exceed the permissible value.

Δp_{II} is only active if the curves for Ranges I and III intersect curve II, as the pressure rise in this situation will exceed the permissible value:

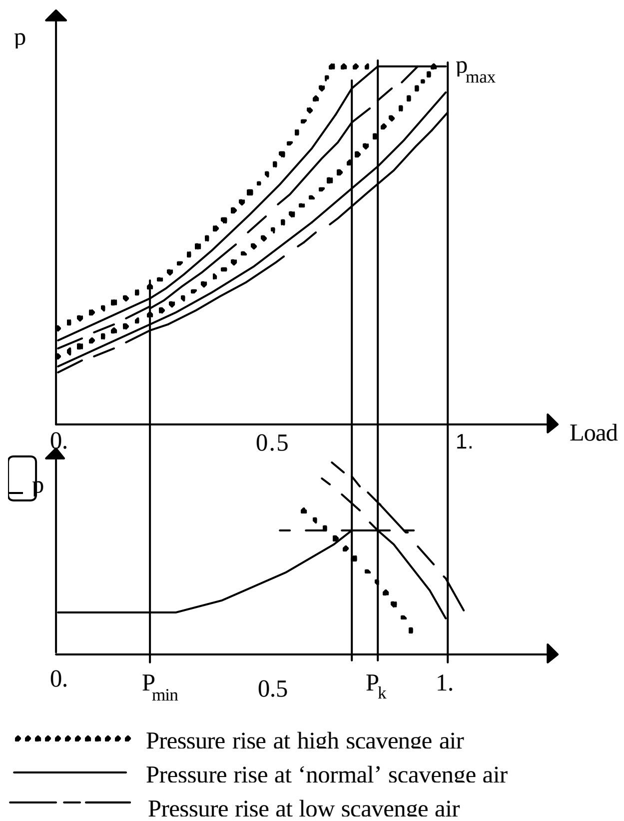
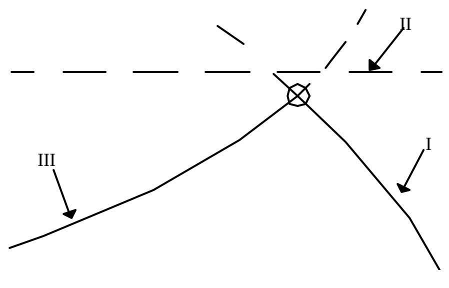
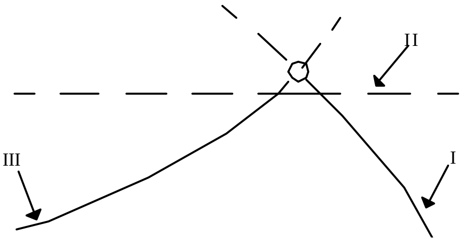


Fig. 3

If the scavenge air pressure is high, the compression pressure will also be high, and the break-point will be displaced to the left, ref. Fig. 3.
In this situation the curves for Ranges I and III will intersect below curve II, and Δp_{II} will therefore not be active.



At low scavenge air pressure, the compression pressure will decrease correspondingly, and the breakpoint will be displaced to the right, ref. Fig. 3. In this situation Δp_{II} is active.



Range III: In the low load range the pressure rise is calculated as a reduction proportional to the load. This means that fixed control has been introduced in which the pressure rise is controlled as a function of the engine speed (rpm) and fuel pump index.

$$\Delta p_{III} = \left(\frac{\Delta p_k - \Delta p_{min}}{P_k - P_{min}} \right) (n_r \times I_r - P_{min}) + \Delta p_{min}$$

This expression can also be written as:

$$\Delta p = k_1 \times \Delta \text{load} + k_2 \quad \text{where}$$

- Gradient coefficient $k_1 = \left(\frac{\Delta p_k - \Delta p_{min}}{P_k - P_{min}} \right)$

- – load = $n (I - I_0)$ = $nI - nI_0$ = $nI - P_{min}$ n = engine speed; $I - I_0$ = effective fuel pump index

- $k_2 = - p_{min}$

n_r and I_r are internal values in the governor: 0.0 ‘relative’ rpm = 0 rpm
1.0 ‘relative’ rpm = MCR rpm
0.0 ‘relative’ index = Fuel pump zero offset (index where injection is just possible)
1.0 ‘relative’ index = MCR index

The other parameters are obtained from the performance and testbed data.

Range IV:

$$\Delta p_{IV} = \Delta p_{min}$$

In the manoeuvring range it is desired to avoid changes in the VIT-index, and therefore the pressure rise is kept constant at minimum value. In practice, the pressure rise is set to $\Delta p_{min} = \Delta p_{MCR}$.

Range V: Is a fixed controlled upper limit. The purpose of this function is exclusively to protect the engine against an excessively high maximum pressure in the event that the scavenge air pressure sensor drifts.

If Range V is the active limit, an alarm is released.

$$\Delta p_V = \frac{\Delta p_k - \Delta p_{MCR}}{1 - P_k} \left(1 - n_r \times I_r\right) + \Delta p_{MCR} + \Delta p_{max,control}$$

The pressure rise in Range I was calculated as:

$$\Delta p = p_{max} - k_c \times p_{sc}$$

The pressure rise could also have been calculated using the following formula, as the pressure rise is reduced inversely proportional to the load in the high load range. However, the following formula represents a fixed control of the pressure rise and does not allow the possibility of compensating for ambient conditions:

$$\Delta p = \frac{\Delta p_k - \Delta p_{MCR}}{1 - P_k} \left(1 - n_r \times I_r\right) + \Delta p_{MCR}$$

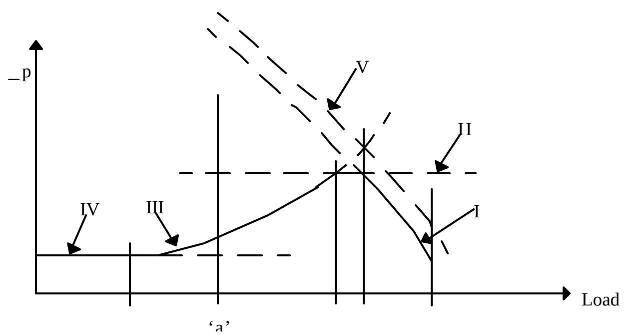
Thus the safety margin against an excessively high maximum pressure corresponds to $p_{max,control}$.

Selection of active range:

The five ranges of pressure rise mentioned above are calculated continuously, and the governor selects which range is to be active based on the following relation:

$$\Delta p = \min \left[\Delta p_I, \Delta p_{II}, \Delta p_V, \max\left(\Delta p_{III}, \Delta p_{IV}\right)\right]$$

The following example shows how the governor selects the range which is to be active:



If the actual loading of the engine corresponds to ‘a’, the active range is selected as follows:

First Ranges III and IV are examined, and the maximum value is chosen:

$$\Delta p = \min\left[\ldots\ldots\ldots\ldots\ldots\ldots,\ \max\left(\Delta p_{III}, \Delta p_{IV}\right)\right]$$

p_{III} has a value that is larger than – p_{IV}.

Then the maximum value (– p_{III}) just found is compared with Ranges I, II and V:

$$\Delta p = \min\left[\Delta p_{I}, \Delta p_{II}, \Delta p_{V}, \ldots\ldots\ldots\ldots\ldots\right]$$

and the minimum value is chosen as the active signal, in this case – p_{III}.

Conversion from pressure rise [bar] to output signal [mA]:

The output signal (4–20 mA), which controls the I/P-converter, is calculated using:

$$I = k_I\left(\Delta p + p_{offset}\right) + 4\left[mA\right]$$

where k_I is the conversion factor from the calculated pressure rise to the output signal of 4–20 mA.

Rate of change of the output signal

To avoid the risk of instability in other parts of the fuel regulating system influencing the VIT, it is necessary to be able to adjust the rate of change of the output signal. For this purpose a ramp function has been introduced (which corresponds to the function of the throttle non-return valve in the ‘mechanical’ VIT system).

The ramp function is adjusted differently for an increasing and a decreasing signal, so that the signal (and thus the VIT-index) slowly increases and quickly decreases. The slowly increasing signal provides a stable VIT system and the quickly decreasing signal prevents sudden reductions in load above the breakpoint from causing excessive maximum pressures.