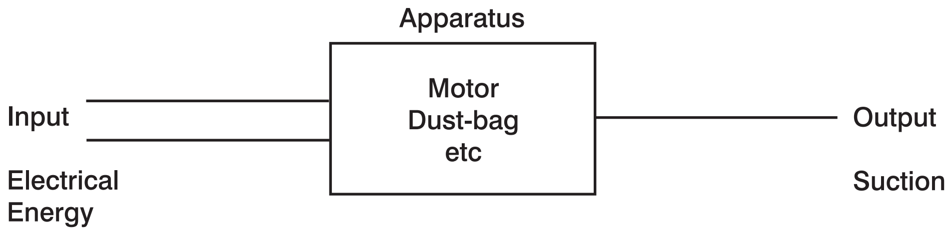
16 October 1967

From Eric Parry

Particularly relevant to our Work, and especially to Self-Remembering

Feedback and Control

Many devices operate such that the input and output circuits are independent in the sense that they are connected only through the apparatus (motor, machinery, amplifier, 'black-box', etc.) which acts as the transforming link between the input and output energies. e.g. take an ordinary vacuum cleaner as in Figure 1.



Vacuum Cleaner

The input signal is the mains voltage fed into the plug, and the output is the suction achieved at the working end of the cleaner. With such devices – known as open loop systems – there is a constant relation between the given input and the derived output, which can be expressed as:

$$Vo = A \bullet Vi \qquad ....(1)$$

where Vo = output signal
Vi = input signal

and A is known as the transfer function of the system.

Where Vo and Vi are the same energy forms e.g. in a voltage amplifier, then A has no dimensions – it is just a number and is then known as the Amplification of the system.

Now A is not necessarily constant, for the apparatus may be dependent upon some factor such as temperature, frequency, amplitude, mains voltage, etc. and when one or more of these external factors operates, the properties of the system will change, i.e. A will change.

$$\text{Thus } \frac{Vo}{Vi} = A\ (\equiv f(x),\ f(y)\ ....\ f(z)) \qquad ....(2)$$

where $f(x)$, $f(y)$, $f(z)$ are simply functions of some external factors.

There is no control of the external parameters in a simple open loop system, and the precision of the process will be subject to the fluctuations of the outside influences.

A feedback system is one in which a signal dependent upon the output is fed back to the input of the system. Since the input signal is thereby altered, the value of the output will change.

i.e. a fraction of the output itself, by changing the input, is used to affect the output.

Consider a voltage amplifier with and without feedback as in Figure 2:

Figure 2a. Open loop amplifier circuit, No feedback.

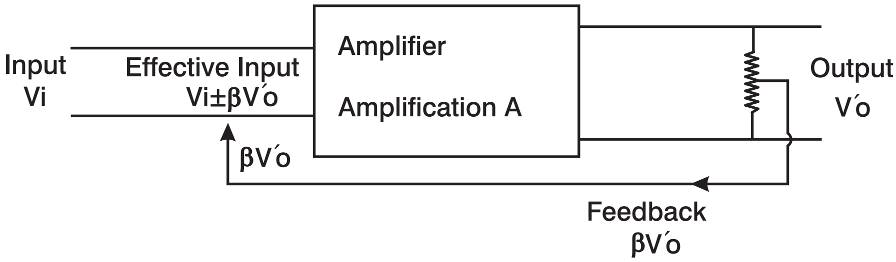


Figure 2b. Closed loop amplifier with feedback.

β is the fraction of the output taken as feedback. Thus the feedback voltage is $\beta V'_o$.

The effective input depends on the relation of the feedback to the input signal.

When feedback is added to Vi it is called *positive feedback* and the effective input is then

$Vi + \beta V'_o$

When feedback is subtracted from Vi it is called *negative feedback* and the effective input is then

$Vi - \beta V'_o$

Positive feedback leads to instability, and *negative feedback gives control.*

For negative feedback,

effective input = $Vi - \beta V'_o$

Since the amplification of the forward loop is A,

then

$V'_o = A \times \text{effective input}$

$= A\,(Vi - \beta V'_o)$

or $V'_o\,(1 + \beta A) = AVi$

i.e. $\dfrac{V'_o}{Vi} = \dfrac{A}{1 + \beta A}$ .... (3)

Now from (3), if A is very high,

then the relation of the output to the input, i.e.

$\dfrac{V'_o}{Vi}$ is equal to $\dfrac{A}{\beta A} = \dfrac{1}{\beta}$

i.e. for very high A, the properties of the system depend almost entirely on the feedback fraction, so that external influences in the amplifier (temperature, frequency, etc.) are excluded.

Under this condition, viz:

$\dfrac{V'_o}{Vi} = \dfrac{1}{\beta}$

if ß = 1, i.e. if the total output is used as feed-back, then

$$\frac{V'o}{Vi} = 1$$

or $V'o = Vi$

i.e. the output follows the input perfectly and control is perfect.

Of course, the cost of this perfect control is that the amplification of the feedback *system* is low, despite the fact that the forward loop has high amplification A.

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To summarise:

Relation of Output to Input $\frac{(Vo)}{(Vi)}$

No feedback $\frac{Vo}{Vi} = A$ { A subject to external influences ∴ no control.

With Negative feedback $\frac{V'o}{Vi} = \frac{A}{1+\beta A}$

$\simeq \frac{1}{\beta} \simeq 1$ { A excluded, i.e. no effect from external influences ∴ good control.

(When A is very high)
(and $\beta = 1$)

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Feedback System of Directed Movement

A man requires to pick up an object. His brain controls a source of power – his muscles – to direct his arm towards the object. (See Figure 3)

A visual impression of the desired position of his hand (i.e. the position of the object) sends a nerve impulse, as the input signal, to the brain which then switches on the power. His hand

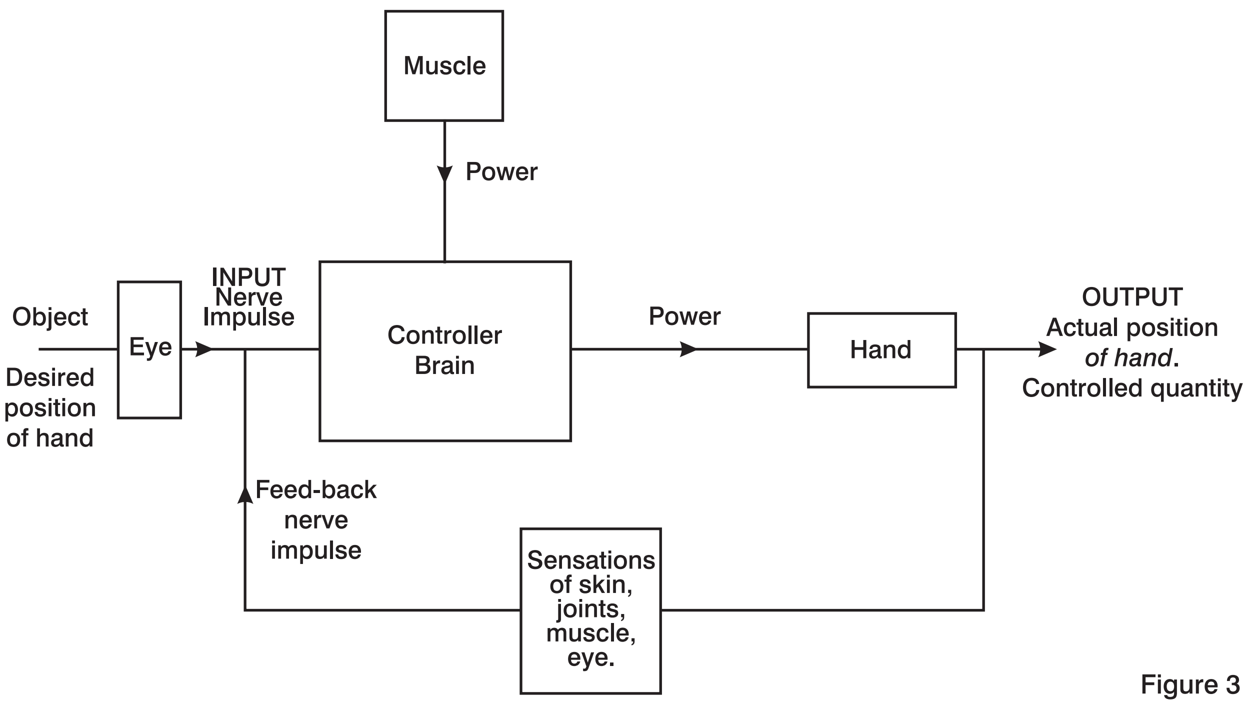

Figure 3

moves. This is the forward loop, and with no feedback his hand would continue to move so long as the input signal was available, i.e. so long as he saw only the desired position of his hand. To stop his hand moving, a nerve impulse in opposition to the input signal is required, i.e. negative feedback. To achieve this, sensations from the skin, joints, muscles, etc. of the *actual* position of his hand send nerve impulses to the input.

The *effective input* to the controller is thus a combination of nerve impulses in opposition derived from comparison of the actual and desired positions of his hand.

Control is thus achieved.

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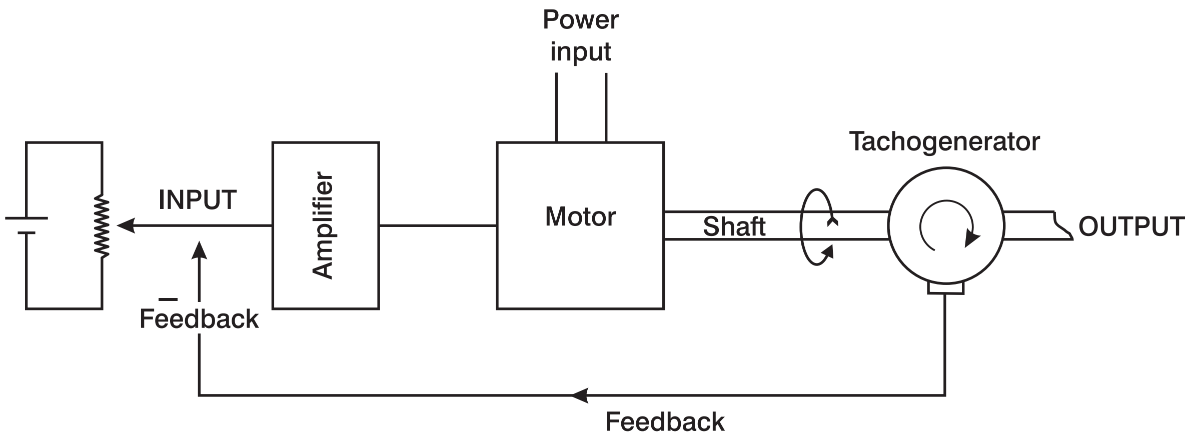
Self-Governing Circuit – Constant Speed Motor



It is required to have a constant speed motor.

When the motor is running, a tachogenerator mounted on the shaft produces a small voltage proportional to the speed of the motor. This voltage is fed back in opposition to the input signal, which is a small voltage representing the required speed.

The condition of equilibrium is that no output should reach the motor from the amplifier. This condition is reached when the feedback voltage is just equal to the input signal, i.e. when the speed is exactly proportional to the input signal.

If the motor runs faster than required, the feedback voltage increases and is greater than the input signal. An amplified negative voltage is fed to the motor windings which decreases the field and the motor slows down.

If the motor runs slower than required, the feedback voltage decreases, becomes less than the set input signal, so that a positive voltage is fed to the motor windings which increases the field. The motor then speeds up.

Feedback ensures corrective action to give constant speed.

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