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(54) AUTOMATIC CONTROL SYSTEM WITH INTEGRATOR OFFSET

(71) We, BARBER-COLMAN COMPANY, a Corporation organised under the laws of the State of Delaware, United States of America, of 1300 Rock Street, Rockford, Illinois 61101, United States of America,

do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates generally to automatic control systems. More specifically, it relates to electric control systems wherein the control signals utilized are combined functions of a proportional signal and the integral and derivative thereof.

Automatic control systems are known in the art. Such systems receive electrical signals representative of a condition of an element to be controlled and compare that signal with a reference to produce an error signal. A particular application of such control systems has been as governors controlling the speed (RPM) of internal combustion engines.

In many applications it is desired to control engine RPM to maintain constant speed in spite of variations of engine load. It is desirable to provide a system wherein the transient response, that is, the response time of the engine and the control system, due to a change in operating conditions, is minimized. This avoids over speed, hunting and instability conditions potentially damaging to the system.

An automatic control system having the characteristics desired for the aforementioned uses is disclosed in U.K. Patent No. 1,507,559. In that patent an automatic control system is described in which engine speed is sensed by a magnetic pick-up coil. After wave shaping and amplification the wave form is applied through an isolating switch arrangement to the input of an operational amplifier. This amplifier compares the average DC level against a reference to generate an error signal. The error signal is then differentiated and integrated with respect to time. A signal proportional to the error signal, its integral and its derivatives are combined to produce a control signal for operating an actuator device which may control a fuel valve or throttle linkage. By use of a feedback element associated with the actuator, accurate control over the device is obtained.

In order for safe operation of the controlled device, it is often necessary to provide one or more external condition limit circuits. Such circuits generate an overriding control signal in the event that a detected condition occurs. Such conditions include excessive engine temperature, excessive smoke, improper manifold pressure, and the like. When such a condition occurs, it is desired to override the automatic control circuit regardless of the normal operating conditions, such as engine speed, and to lower the operating speed of the engine or shut it down altogether depending upon the considerations involved.

When a limit control overrides the automatic control system, the integrator circuit of the control system is "fooled" by the continued operation of the engine at a value other than that specified by the automatic control. This causes the integrator to begin operating in a manner disadvantageous to precise control when the controlling external limit is removed.

If no provision is made for offsetting the integrator during operation of a limit, then for a considerably long period of time after the external limit is removed the integrator will cause the automatic control system to operate in an improper manner as, for example, hunting for the set point. This is because the integrator output is utilized as one measure of the amount of error between the set point speed and the actual operating speed. Therefore, if the integrator is considerably away from its proper value, the circuit will not provide as precise control as is otherwise obtainable.

Embodiments of the invention seek to provide an integrator offset circuit which will prevent the integrator from saturating during a period of operation in which an external limit overrides the automatic control system.

Embodiments of the invention also seek to provide an integrator offset circuit which, responsive to the presence of an external control condition, maintains an integrator circuit in a desired operating region for the duration of the applied external limit signal.

Embodiments of the invention further seek to provide an integrator offset circuit for an automatic control system.

According to the invention there is provided an automatic control circuit including means for generating an error signal, means for generating the integral thereof, means for producing a control signal from said error signal and said integral and including means responsive to the detection of an external condition for producing an external limit signal to override said control signal, and means for altering the input to said integrator means when said external limit signal overrides the control signal to maintain the output of said integrator means in the normal operating region for subsequent control signal generation after said external limit signal ceases to override said control signal, said altering means including an operational amplifier applying a signal to said integrator means input of a polarity opposite to the polarity of said error signal and of a magnitude substantially equal to or greater than said error signal.

An embodiment of the invention will now be described by way of example with reference to the accompanying drawings in which:—

Figure 1 is a block diagram of an automatic control circuit illustrating schematically an integrator offset circuit according to the invention.

Figures 2A and B are integrator output wave forms useful in understanding the circuit of Figure 1.

Referring to Figure 1, a block diagram of a control system according to the invention is illustrated. The RPM of a prime mover, such as a diesel engine or similar internal combustion engine, is detected by a magnetic pick-up coil 10. The sinusoidal wave form produced by the coil is received by a wave shaping and amplifier circuit 12 which produces square wave pulses therefrom. The series of pulses, the frequency of which is proportional to the detected RPM of the engine, is fed through an electronic switching and noise isolation circuit 14. This circuit produces an average DC voltage level proportional to the received pulses from the wave shaper block 12. The average DC signal is applied to the difference amplifier circuit 16 for producing an error signal at junction 18. The error signal is integrated by integrator 20 and differentiated by a differentiator 22. The signal proportional to the error signal, its integral and its derivative are summed at junction 23 and applied to a control signal generator 24, the output of which is provided at junction 26.

A control element, the state of which is controlled by the signal at junction 26, may be constituted by any number of devices. In the case of an engine governor, the control element may be a fuel valve operated by an actuator. The position of the valve is determined by the energization state of the actuator solenoid coil, such as, coil 28. The state of energization is, of course, a function of the average current through the coil. In order to provide a signal representative of the actual position of the valve, a feedback element, such as a potentiometer, is mechanically connected to the solenoid actuator so as to produce a feedback voltage representative of position.

The feedback element 30 applies a voltage to the junction 26. Junction 26 is the input to a difference amplifier 32, which amplifier compares the magnitude of the control signal with the magnitude of the feedback signal. The difference between the signals, if any, is supplied as one input to the amplifier circuit 32. A sawtooth wave oscillator 34 is applied to the other input of the difference amplifier 32 to produce a pulse width modulated signal at the output of the amplifier which determines the average current flowing through the actuator coil 28.

The circuit thus far described provides an automatic control circuit to maintain an engine or other prime mover at a regulated operating condition, for example, constant speed. Aditionally, the circuit may include the provision of an external limit override circuit 36 which can override the signal from the control signal generator 24 upon detecting selected conditions, such as, high temperature, excessive smoke, improper manifold pressure, etc.

When one of the monitored external limited conditions occurs, the normal operation of the control circuit is altered. Instead of driving the difference amplifier 32 based on the control signal produced by the amplifier 24, amplifier 32 is instead driven by a signal provided from the condition limiting circuit 36 via line 38. The amplifier 24 is effectively removed from the circuit by means of diode 40. Normally the control signal is provided via diode 40 to junction 26. This signal is normally negative. If no external limit signal is present at the junction 26, diode 40 conducts. However, when an external condition limit signal is provided on line 38, which signal is more negative than the control signal, diode 40 is reverse biased and will not conduct. The external signal from line 38 together with the feedback signal from the position detector 30 then determines the output from the difference amplifier 32.

When an external override occurs, the integrator 20 is unaware of this condition. In the absence of circuitry according to the present invention, the integrator circuit merely detects the fact that the controlled device, i.e., the prime mover, is no longer operating in the selected range due to the increase in the error signal at junction 18.

The output from the integrator under such a circumstance is illustrated in Figure 2A. This graph is a schematic representation of the integrator output versus time. Over segment 1 the circuit is operating normally and the output from the integrator is substantially constant assuming the engine is performing normally. Over segment 2 an external limit condition has overriden the normal operation of the circuit and slow the engine down due, for example, to excessive heat or smoke. As the engine RPMs decrease, the error signal will increase causing an increase in the integrator output which continues until the integrator enters saturation. Stated differently, the integrator sees a constant error at junction 18 and goes to its maximum output in an effort to generate a signal which will correct the error.

During segment 3 the limit override ceases and control of the engine is returned to the control circuit. However, since the integrator has been allowed to reach positive saturation, its output is now far from the desired level for quickly achieving and maintaining set point operation of the prime mover. Its output will, over a period of time, return to the proper level but for the period indicated at segment 3 the automatic control circuit will not provide highly satisfactory control. Offset or droop is likely to occur. In order to overcome this problem, particularly where external limit conditions occur on a frequent basis, it is desirable to offset or reset the integrator 20 during periods when the external condition limit is in effect. Stated differently, it is desirable to clamp to a selected level the output of the integrator during the occurrence of an external condition limit.

The effect of clamping or offsetting the integrator is illustrated in Figure 2B. This graph is the same 2A over segment 1, the normal operation of the control circuit. Over segment 2, however, when the external limit overrides circuit operation, the offset circuit to be described prevents the integrator from reaching positive saturation and maintains it at a value at or slightly below its value at the time the limit override went into effect. Over segment 3, when the limit is removed, the integrator quickly resumes its proper output level for providing accurate information to the control signal generator 24.

Referring again to Figure 1, the offset or clamping circuit according to the invention is illustrated. The occurrence of an external limit condition from circuit 36 is detected by a diode 42 placed across the inputs of an operational amplifier 44. Amplifier 44 acts as a switch and goes from positive saturation to negative saturation depending upon whether diode 42 is forward or reversed biased. As will be apparent, diode 42 is forward biased when the limit circuit 36 is overriding the automatic control circuit since the signal produced by the limit circuit is negative. Current is conducted from the positive voltage source 46 through resistor 47, line 38, and diode 42. This forward biases the diode sending the amplifier 44 into positive saturation.

Amplifier 44 is an operational amplifier. The output of the amplifier is provided via resistors 48, 50 and diode 52 to junction 54 of the integrator. When the external limit is in effect, the amplifier 44 goes into positive saturation. The output of the amplifier is then provided to the junction 54 where it is subtracted from the error signal generated by amplifier 16. That is, when a limit signal occurs reducing the engine RPM from that maintained by the automatic control circuit, an error signal of a first polarity, for example, negative, is produced at terminal 18. In turn, this error signal is provided to terminal 54 and integrator 20.

The signal generated by the offset or clamping portion of the circuit is of an opposite polarity from the error signal, in this case positive. Its magnitude is chosen to be of a value equal to or greater than the error signal normally encountered over a selected operating range for a given application. If the clamping signal provided on line 56 slightly exceeds the error signal, the waveform illustrated in Figure 2B, segment 2, is obtained. The value provided on line 56 can be adjusted as necessary for a given application.

When the external limit ceases to block operation of the control signal generator 24, diode 42 will cease conduction. Amplifier 44 will then saturate low and the positive signal will be removed from line 56 permitting the integrator 20 to respond to the error signal provided from terminal 18.

While we have shown and described embodiments of this invention in some detail, it will be understood that this description and illustrations are offered merely by way of example, and that the invention is to be limited in scope only by the appended claims.

WHAT WE CLAIM IS:—

1. An automatic control circuit including means for generating an error signal, means for generating the integral thereof, means for producing a control signal from said error signal and said integral and including

means responsive to the detection of an external condition for producing an external limit signal to override said control signal, and means for altering the input to said integrator means when said external limit signal overrides the control signal to maintain the output of said integrator means in the normal operating region for subsequent control signal generation after said external limit signal ceases to override said control signal, said altering means including an operational amplifier applying a signal to said integrator means input of a polarity opposite to the polarity of said error signal and of a magnitude substantially equal to or greater than said error signal.

2. A circuit according to Claim 1, wherein said means for altering includes means for detecting the presence of said external limit signal.

3. A circuit according to Claim 1 or Claim 2, wherein said operational amplifier is connected as a difference amplifier.

4. A circuit according to any preceding Claim, wherein said integrator means is an operational amplifier connected as an integrator.

5. A circuit according to Claim 2 or any one of Claims 3 and 4 when appended to Claim 2, wherein said detecting means is a diode placed in circuit with said means for producing an external limit signal.

6. A circuit according to Claim 5, wherein said operational amplifier of said altering means is connected as a comparator, the inputs of which are connected across said diode, a first output from said amplifier resulting if a limit signal is detected by said diode while a second output, of opposite polarity, resulting if no limit signal is detected.

7. A circuit according to Claim 5 or Claim 6, when Claim 5 is appended to Claim 3, wherein said integrator means is an operational amplifier connected to integrate said error signal and wherein said difference amplifier output is also connected to the input of said integrator amplifier, said first output being of opposite polarity and of substantially the same magnitude as said error signal whereby during the existence of a limit override the integrator amplifier output is clamped to its approximate value immediately prior to the occurrence of the limit override.

8. An automatic control circuit substantially as herein described with reference to and as shown in the accompanying drawings.

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1561009 COMPLETE SPECIFICATION

2 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 1

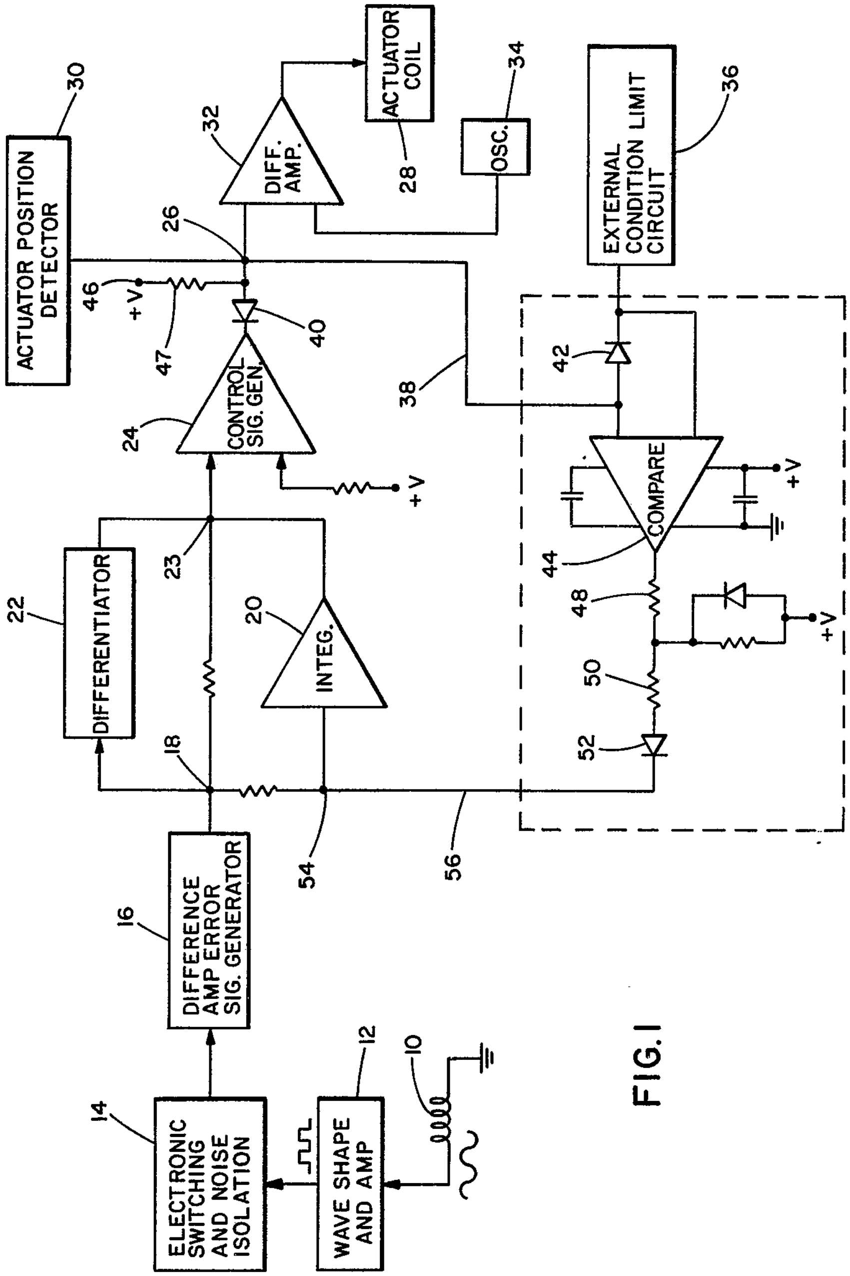

FIG.1

1561009 COMPLETE SPECIFICATION

2 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 2

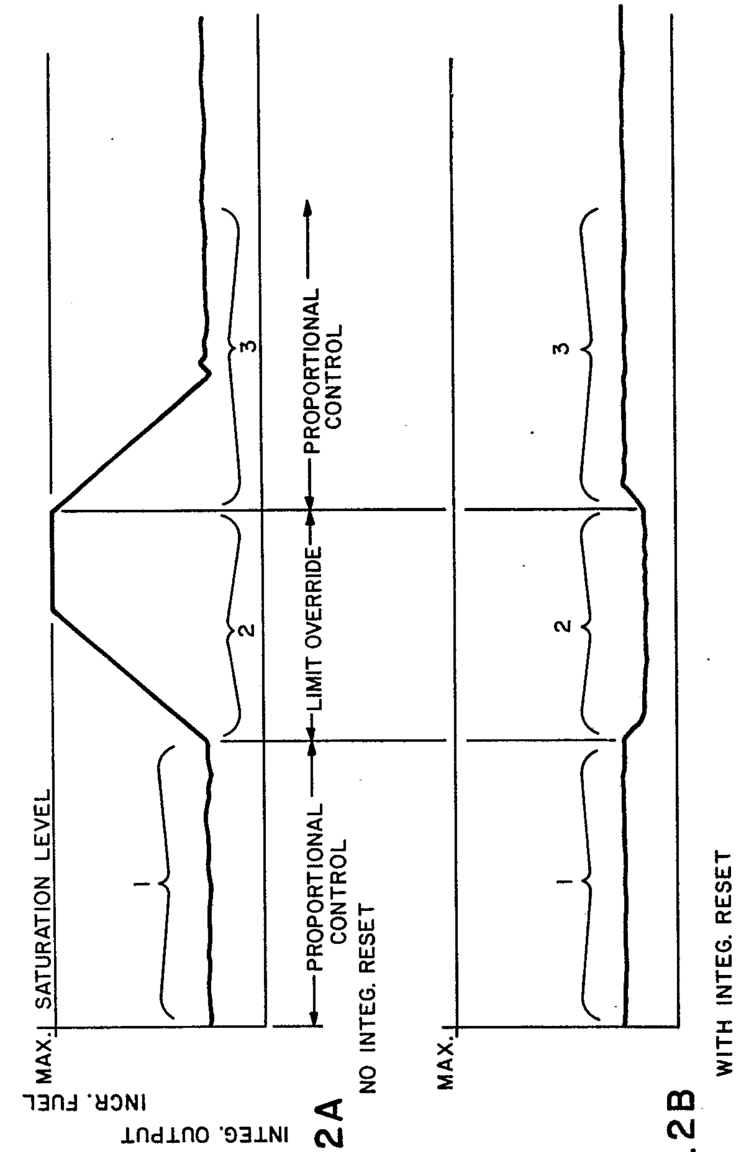

FIG. 2A

FIG. 2B