

[54] **ELECTRONIC CONTROL SYSTEM FOR
INTERNAL COMBUSTION ENGINES**

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[58] **Field of Search**.....123/32 E, 32 EL, 140.3, 119

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[57] **ABSTRACT**

An injector injects fuel in each operating cycle, the quantity varying in dependence upon fuel control signal. A desired speed signal is furnished by circuitry associated with the gas pedal. An actual speed signal is also furnished. High gain direct amplifier means having an input circuit and a feedback circuit are adapted to furnish the fuel control signal as a function of both the desired speed signal and the actual speed signal. Various configurations of input circuits and feedback circuits, as well as amplifier output circuits, are illustrated for shaping the characteristic fuel-speed lines which determine motor operation.

50 Claims, 16 Drawing Figures

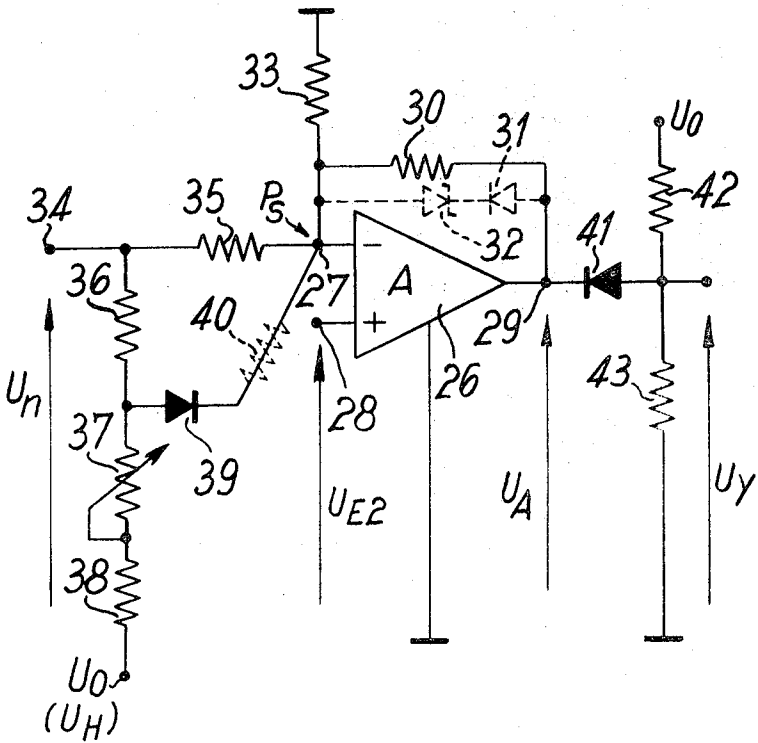


FIG. 1

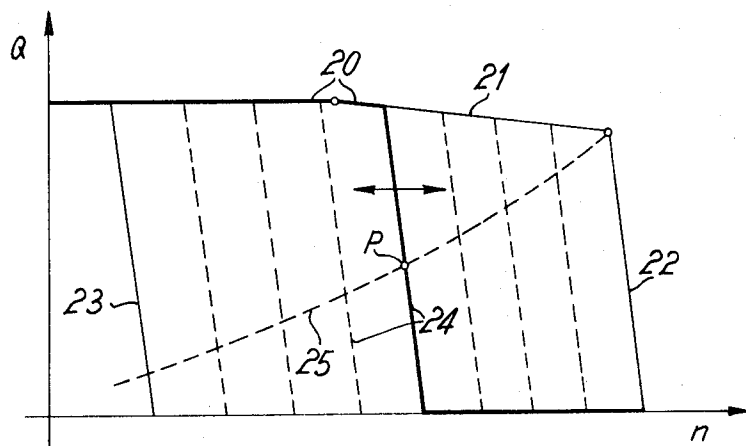
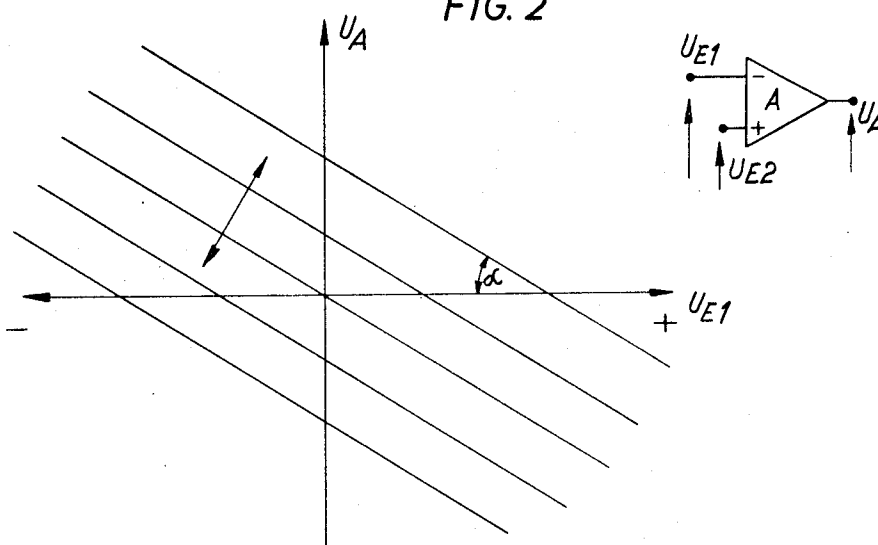
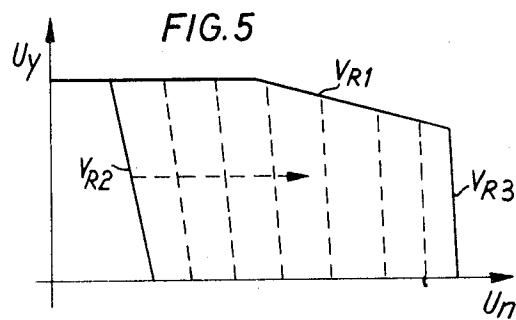
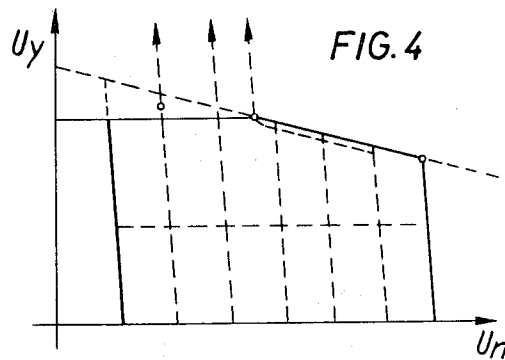
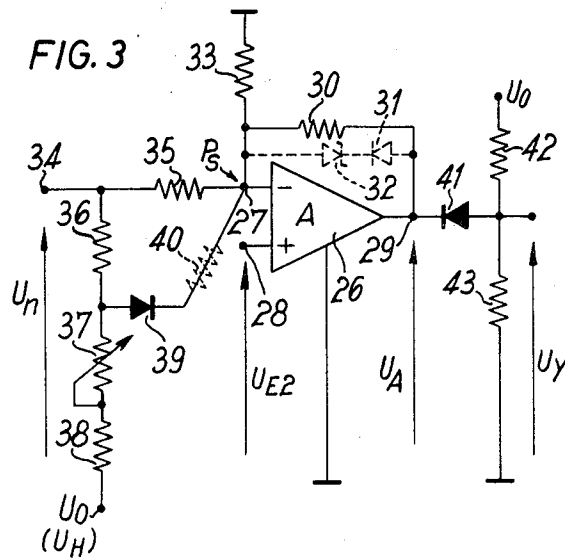


FIG. 2



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FIG. 6

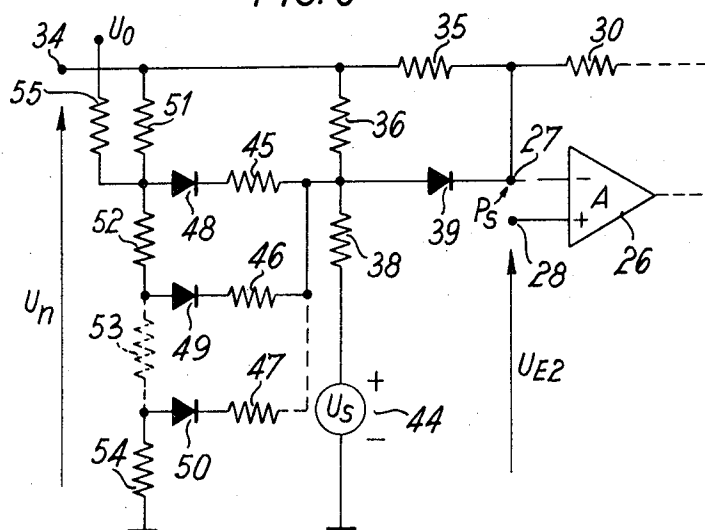
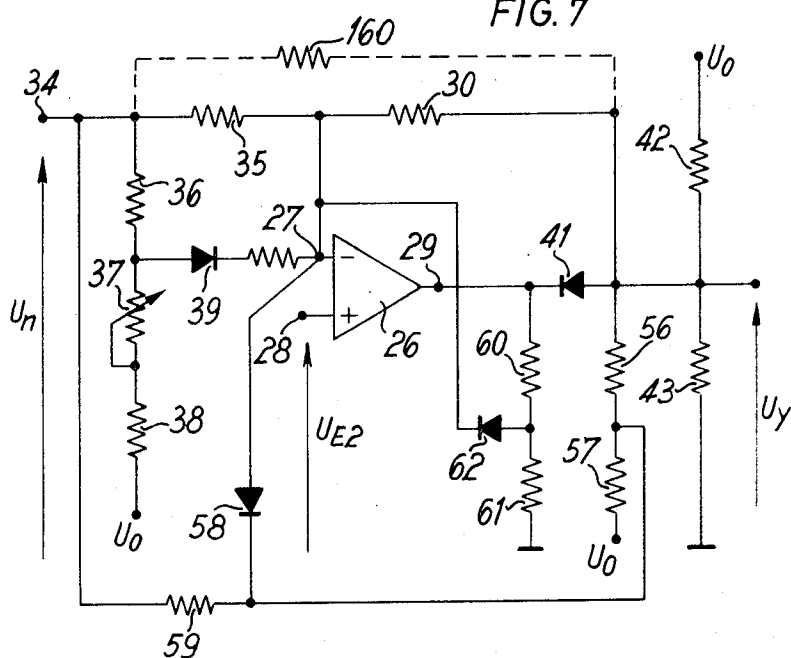


FIG. 7



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FIG. 8

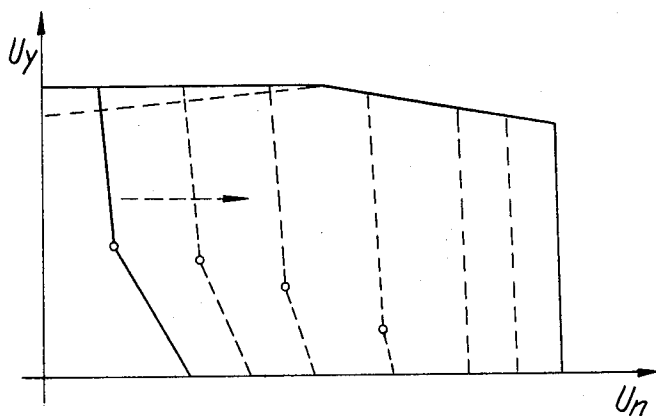
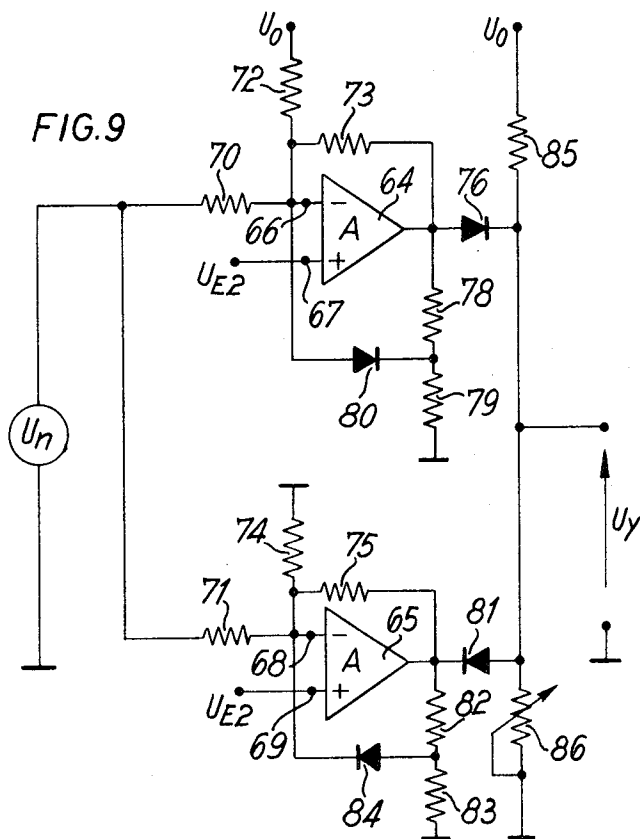


FIG. 9



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FIG.10

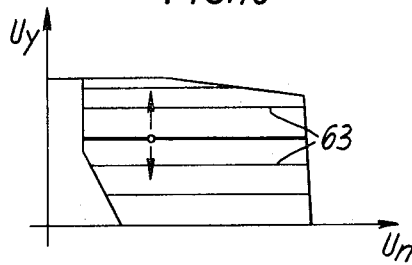
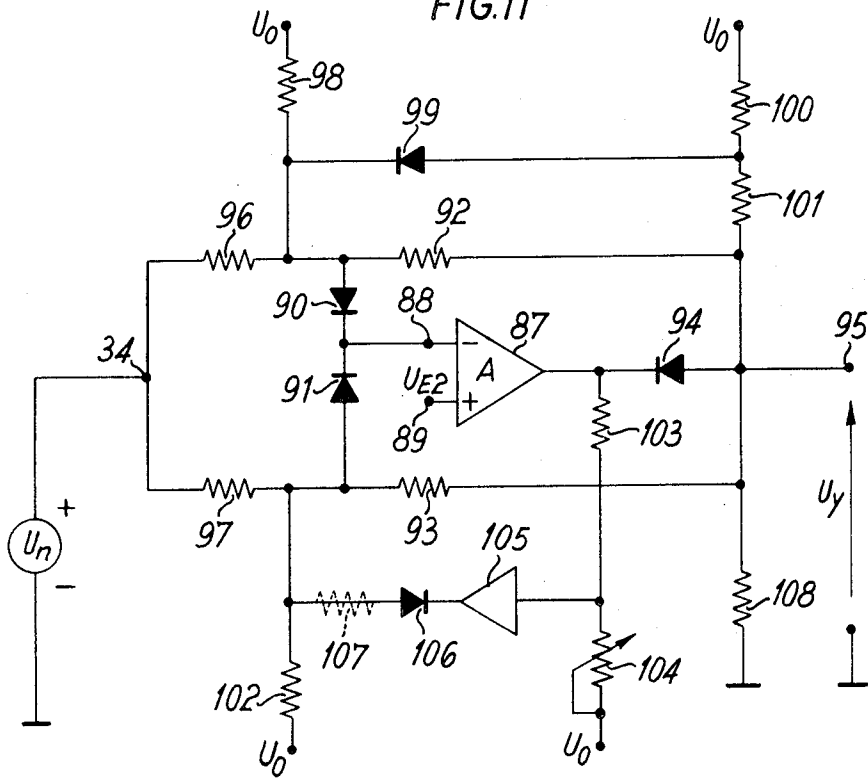
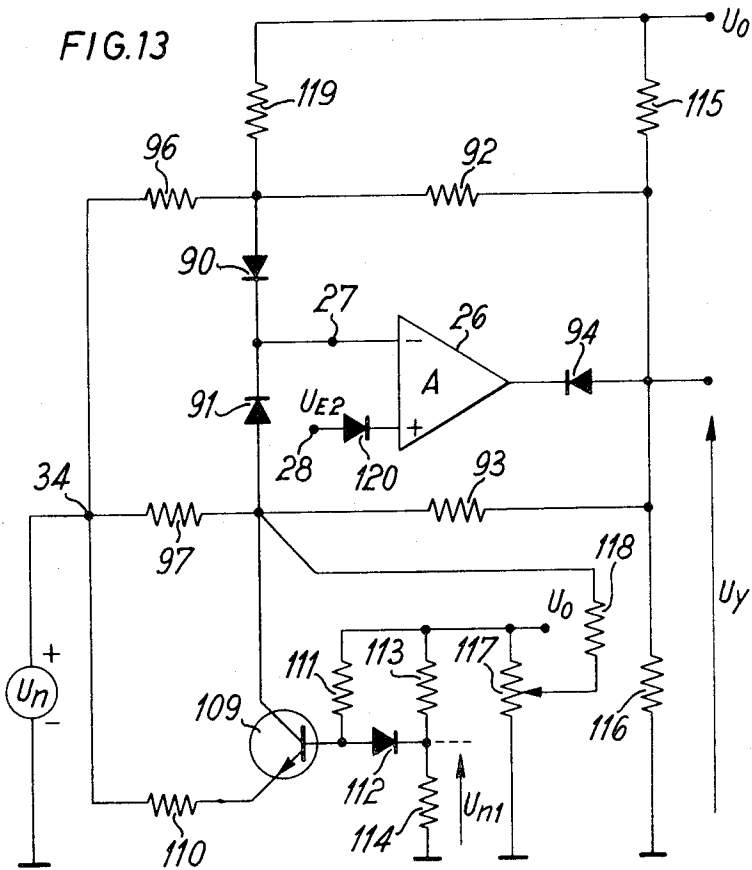
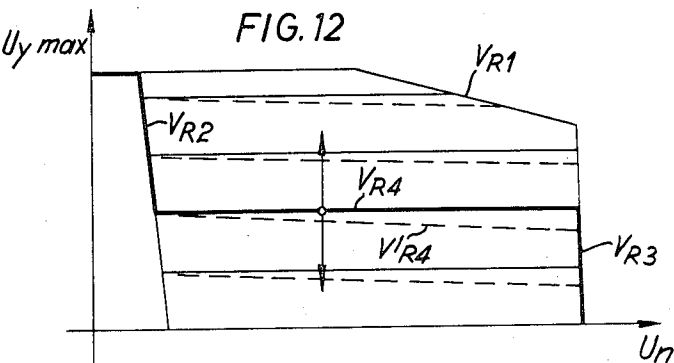


FIG.11



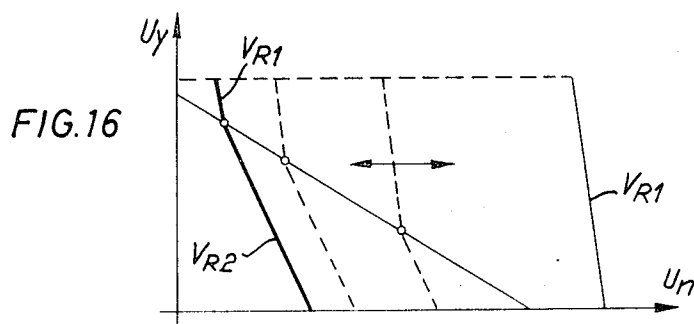
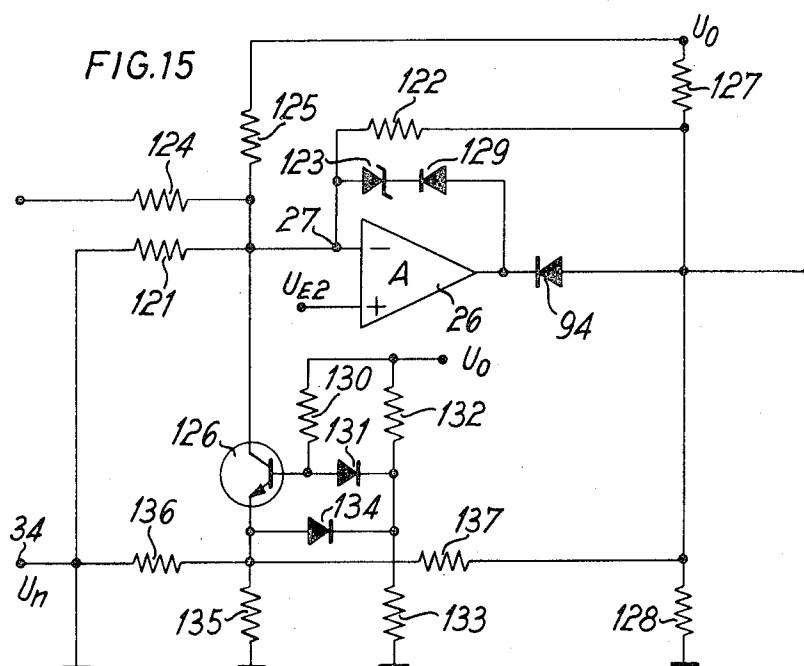
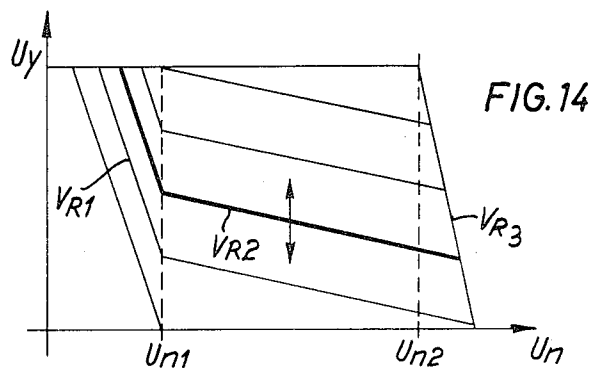
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ELECTRONIC CONTROL SYSTEM FOR INTERNAL COMBUSTION ENGINES

BACKGROUND OF THE INVENTION

This invention relates to control systems for internal combustion engines. It is particularly applicable to Diesel motors.

Two types of control systems are known for controlling the operation of Diesel motors. The first type of regulating or control system may be used to effect any desired motor speed between the minimum no-load speed and the maximum permissible speed of the motor. The control system then tends to keep this speed constant, independent of the motor load.

The second type of regulator which is known is a type of regulator which operates upon the extreme values of speed only. That is, it has the function to maintain the lowest permissible no-load speed of the motor and to limit the speed if the speed tends to exceed a predetermined maximum value. It does not operate at all in the region between the two extremes of speed.

Both hydraulic and mechanical types of regulators are known to accomplish the above functions. For these, the regulator is generally directly connected to the means which vary the quantity of fuel. They generally do not develop enough control power for low-engine speeds. Other conventional regulators use auxiliary power sources, but are very complicated and require a great deal of equipment.

SUMMARY OF THE INVENTION

It is thus the object of this invention to furnish a control system for an internal combustion engine, which will not have the above-mentioned drawbacks.

This invention comprises a control system for internal combustion engines which comprises at least one injector means for injecting fuel in dependence upon a fuel control signal. Means are provided for furnishing a desired speed signal corresponding to the desired engine speed. Means are also provided for furnishing an actual speed signal corresponding to the actual engine speed. Finally, high gain direct current amplifier means having an input circuit and a feedback circuit are provided. The output of these high gain direct current amplifier means is adapted to furnish the fuel control signal in response to the desired and actual speed signals.

Changes in the input circuit and the feedback circuit allow the matching of a wide variety of fuel-speed motor characteristic lines.

The type of control system has the advantage that it is very flexible in being adapted to various motor constants and operating conditions. The possibility exists that all control systems for all types of motors may be constructed using the same basic elements, or standard building blocks. Furthermore, this type of control system offers a great reliability even under the rough operating conditions in a commercial vehicle. For example, the temperature range in which the control system must function correctly lies between at least -20°C . and $+80^{\circ}\text{C}$. A further advantage is of course the ease of reproducibility of the parameters corresponding to the characteristic lines. Also, as stated above, the control systems may be easily modified to accommodate any desired motor type. If appropriate non-

linear feedback elements are used, even characteristic lines having breaks in the characteristics may be duplicated.

The novel features which are considered as characteristic for the invention are set forth in particular in the appended claims. The invention itself, however, both as to its construction and its method of operation, together with additional objects and advantages thereof, will be best understood from the following description of specific embodiments when read in connection with the accompanying drawing.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 shows the fuel-injected speed characteristic lines of a motor;

FIG. 2 shows the input-output characteristic lines of a differential amplifier, as well as a block diagram of such an amplifier;

FIG. 3 is the circuit diagram of a simple control system adapted to regulate speed over the whole range;

FIG. 4 are the characteristic lines applicable to an internal combustion engine operating with a control system shown in FIG. 3, wherein the slope of the speed control lines are constant;

FIG. 5 shows characteristic lines wherein the slope of the speed control lines varies;

FIG. 6 shows the input circuit of a control system using an active element for furnishing the desired speed signal;

FIG. 7 is the circuit diagram of a control system for generating speed control lines having a break;

FIG. 8 shows the characteristic lines of a motor using the control system of FIG. 7;

FIG. 9 shows a control system for controlling extreme speed values only, and using two D.C. amplifiers;

FIG. 10 shows the speed-fuel characteristic lines corresponding to the control system of FIG. 9;

FIG. 11 shows a control system for regulating extreme speed values only, and using a single D.C. amplifier;

FIG. 12 shows the characteristic lines associated with the circuit of FIG. 11;

FIG. 13 is a circuit diagram for control system combining the two types of regulation;

FIG. 14 is a characteristic diagram associated with the circuit of FIG. 13;

FIG. 15 is a circuit diagram showing the regulator of the first type having a break in the speed control characteristic lines; said lines also having a variable slope; and

FIG. 16 shows the characteristic lines associated with the circuit of FIG. 15.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The preferred embodiments of the present invention will now be described with reference to the Figures.

FIG. 1 shows the motor characteristics. Plotted along the ordinate, is the quantity of fuel in cubic centimeters per stroke, while the abscissa is in units of rotational speed, that is, revolutions per minute. For facilitating the understanding of the disclosure, the line labelled 20 in FIG. 1 will be referred to as the full-load limiting line, line 21 will be referred to as the full-load matching line, while line 22 will be referred to as the maximum-

speed limiting line. Further, line 23 will be referred to as the minimum-speed limiting line. Within the region defined by the minimum-speed limiting line and the maximum-speed limiting line, the speed control lines may be varied continuously, lines 22 and 23 representing the extreme positions of the speed control lines.

As an example for the quiescent condition of the control system, the intersection P of a load-line 25 with a speed control line which has been adjusted to approximately the center of the region is given. Line 25 of course corresponds to the amount of fuel necessary to effect a given desired speed under a determined, constant load.

FIG. 2 shows a block diagram of a differential amplifier, in this case a high gain direct current amplifier, as well as the characteristics of such an amplifier. In particular, the output voltage U_A is plotted as a function of input voltage applied at a first amplifier input terminal, namely the voltage U_{E1} . The parameter of the characteristics is, of course, the voltage applied at the second amplifier input terminal, namely U_{E2} . With the aid of such an amplifier, it is theoretically possible to generate any desired motor characteristic.

FIG. 3 is a circuit diagram of a simple regulator of the first type, namely, a regulator designed to operate over the whole range of the control line. The direct current amplifier is labelled 26 and has a first amplifier input terminal 27, a second amplifier input terminal 28, and an amplifier output terminal 29. A constant voltage U_{E2} is applied at input 28. A feedback resistor 30 is connected between the output terminal 29 and the input terminal 27. If necessary, as protection against overdriving amplifier 26, a Zener diode 32 in series with a diode 31, may be connected in parallel to resistor 30. Further connected to input 27 is a resistor 33, herein referred to as a fourth resistor, whose function it is to fix the position of line 21. The input terminal of the regulating system, terminal 34, is connected to input terminal 27 of the amplifier by means of a resistor 35, herein referred to as a first resistor. Input terminal 34 has applied to it a voltage U_n , which represents the actual speed signal, and is a voltage proportional to the actual speed of the engine. Also, connected to input terminal 34 is a series circuit comprising resistors 36, 37, and 38. Resistors 36 and 38 are herein referred to as a first and second fixed resistance, while resistor 37 is referred to as a variable resistor. This variable resistor is the means for furnishing a desired speed signal and is connected to the gas pedal, for example. The other end of the above-mentioned series circuit is connected to the D.C. voltage source, U_o . The common terminal of resistors 36 and 37 are connected to the anode of the diode 39, herein referred to as a first diode. The diode has a cathode connected with the first amplifier input terminal 27, while the anode is connected to the common point of resistors 36 and 37. If necessary, a resistor 40 may be furnished between the cathode of diode 39 and terminal 27. This resistor is herein referred to as the fifth resistor. With the output amplifier terminal 29 is connected the cathode of the diode 41. Two resistors 42 and 43 are connected to the anode of this diode. Resistors 42 and 43 are herein referred to as first voltage divider means. Their common terminal is referred to as the first voltage divider terminal. Throughout this application, whenever volt-

age divider means are mentioned, the "voltage divider terminal" will refer to a common terminal of two elements constituting such a voltage divider. Specifically, resistor 42 is connected to the D.C. voltage source, while resistor 43 has its free terminal connected to ground. The voltage U_v generated across resistor 43 constitutes the fuel control signal and serves to effect a proportional movement of the member determining the amount of fuel to be injected during each operating cycle.

The characteristic lines of the above-control system as shown in FIG. 4 will be noted that all speed control lines exhibit the same slope. Below a voltage U_n which depends upon the value of resistor 37, diode 39 is blocked causing the amplification to have the value

$$V_{R1} = -R30/R35.$$

This determines the slope of the full-load matching line 21. As long as the output voltage U_A is larger than the voltage across resistor 43, namely voltage U_v , diode 41 is blocked and $V_R = 0$. This corresponds to the horizontal portion of the full-load limiting line. Alternatively, the terminal of feedback resistor 30 which is not connected to the amplifier input terminal, may be connected to the anode of diode 41. This yields the advantage that the voltage appearing across diode 41 affects the input voltage U_v only as multiplied with the factor V_R/V_o . However, in this case, when the diode 41 is blocked, the feedback has been eliminated in this circuit. Therefore, another feedback network must be furnished in order to prevent the amplifier from becoming overdriven. This network may, for example, comprise a Zener diode 32 and a diode 31.

If the voltage U_n increases sufficiently to cause the diode 39 to become conductive, then the amplification becomes

$$V_{R2} = -R30/R35 \parallel R36.$$

In order that a conductive diode 39 does not cause voltage division of U_n , that is, in order to achieve a constant slope for the speed control lines, by making V_{R2} independent of R_{37} , the impedance of the first voltage divider means, looking back from the anode of the diode, that is, $R36 \parallel R37 + R38$ should be made large compared to the forward resistance of diode 39.

The values of $R37$ and $R38$ determine the region or distance between the minimum-speed limiting line, such as line 23 in FIG. 1, and the speed control line.

The actual position of line 21 may be determined by a combination of resistor 33 in conjunction with the voltage U_{E2} applied to the second amplifier input terminal. This can be accomplished without changing the slope of the line. Of course instead of the passive element for furnishing the desired speed signal, an active element such as a current source with a constant series resistor may be supplied.

It is usually desirable when regulating Diesel motors, that the slope of line 23 is smaller than the slope of line 2 ($V_{R2} < V_{R3}$). For this purpose, a resistor 40, herein referred to as a fifth resistor, is inserted between the cathode of diode 39 and amplifier input terminal 27. When this resistor is used in conjunction with the variable resistor 37, it can be accomplished that the amplification between the line 23 and line 22 varies continuously. In order to satisfy the requirements for a

predetermined region and simultaneously the requirements for the different slopes of the speed control lines at the limiting ends, the resistor 38 may be connected to a corresponding auxiliary voltage supply U_H . In this case, the voltage divider comprising resistor $R_{36}/R_{37} + R_{38}$ is no longer rigidly connected to the potential existing at the first amplifier input terminal 27 and thus acts as a voltage divider for the input voltage U_n within this operating region. A shifting of the speed control lines towards the right, resistor R_{37} is increased and the division of voltage U_n simultaneously decreased. Thus the amplification increases as the speed control line is moved towards the right.

FIG. 6 shows the input circuit of a control system wherein an active element is used to furnish the desired speed signal. This active element is labelled 44. The terminal of resistors 45, 46 and 47 is connected to the common terminal of resistors 36 and 38. The other end of these resistors are respectively connected to the cathodes of diodes 48, 49 and 50. The anode of diode 48 is connected to the common point of resistors 51 and 52, the anode of diode 49 to the common point of resistors 52 and 53, while the anode of diode 50 is connected to the common point of resistors 53 and 54. The other terminal of resistor 54 is connected to ground, while the free terminal of resistor 51 is connected to the input terminal 34. Resistors 51 through 54 form second voltage divider means. This input circuit makes known of the well-known method to generate the effect of a voltage-dependent resistance by means of a plurality of diodes each having a different pre-bias. Under the conditions corresponding to line 23, diodes 48, 49 and 50 are blocked, and diode 39 is conductive. The value U_s signifying the desired speed signal has its maximum value. The amplification then is

$$V_{r2} = -R_{30}/R_{35} \parallel R_{36}.$$

The smaller values of U_s , the transition to the conducting condition of diode 39 takes place for larger values of U_n . The transition into the control line is therefore moved towards the right. For increasing values of U_n , the diodes 48, 49 and 50 each gets switched to the conductive condition independence upon the particular values chosen for resistors 51, 52, 53 and 54. Thus the effective input impedance or resistance is decreased, that is, simultaneously with the movement to the right, the slope of the control line becomes steeper. The distance between breaks in the control line depends, of course, upon the number of parallel diode-resistance circuits furnished in the non-linear input circuit. Thus, in order to provide a finer control of the slopes, further diode must be added to the diodes 48, 49 and 50, as well as corresponding resistors and corresponding additional parts to the second voltage divider means.

Another example of a control regulating system is shown in FIG. 7. The corresponding characteristic lines are shown in FIG. 8. The minimum-speed limiting lines here as a break as is sometimes desirable for reasons of dynamic stability of the control system. This break in the characteristic, as shown in FIG. 8, can be constructed by varying the amplification in dependence on the output voltage. For this purpose, the third divider means comprising resistors 56 and 57 are connected to the anode of diode 41. One end of resistor 57 is connected to the D.C. voltage supply source, the free end

of resistor 56 is connected to the anode of diode 41. The free end of resistor 57 might alternatively be connected to ground. At the third voltage divider terminal, namely the common point of resistors 57 and 56 is connected the cathode of diode 58, herein referred to as the third diode, whose anode is in turn connected to the amplifier input terminal 27. Also connected to the third voltage divider terminal is one end of a resistor 59 whose other end is connected to the input terminal 34. The following may be achieved with aid of resistors 56, 57 and diode 58: When the potential at the third voltage divider terminal, namely the common point of resistors 56 and 57, decreases below the potential existing at the first input terminal 27 of amplifier 26, then the resistance 56 is inserted in parallel to the feedback resistor 30 via diode 58. The amplification then is

$$V_{r4} = -\frac{R_{30} \parallel R_{56}}{\text{Total input resistance}}.$$

The location of the break point can be fixed by means of resistor 57. By way of the resistance 59, the break in the control line is moved towards the bottom of the graph with increasing speed, finally to vanish completely. The changes in slope take place as described in the previous embodiment. Means for preventing amplifier overdrive are also provided. It comprises resistors 60 and 61 connected in series from the amplifier output terminal 29 to ground. A diode 62 has an anode connected to the common point of resistors 60 and 61 and a cathode connected to the first amplifier input terminal. Of course instead of this arrangement, the Zener diode arrangement shown in FIG. 3 may also be used.

Under certain circumstances, it may be necessary to effect a positive slope for the full-load limiting line. This may for example be required for optimal matching of the control system to a pump-motor characteristic. The amplification required in this case generally lies in the region $0 < V_r < 1$ and may therefore be readily achieved by direct coupling of the output voltage divider with the voltage U_n via an additional resistance 160. When diode 41 is blocked, the resistor 160 exerts no influence onto the output voltage U_n , because of the low output impedance of the feedback amplifier 26.

In FIG. 9, there shows an embodiment of the second type of regulator, namely the regulator which serves only to maintain a minimum no-load speed and to limit the maximum permissible motor speed. The characteristic corresponding lines are shown in FIG. 10. Lines 63 indicate output voltages U_r which are proportional to the amount of fuel to be injected per stroke. If the operating point lies within the region of the characteristics, the amplification is zero, the control circuit is broken, and the amount of fuel to be injected may be fixed arbitrarily. The regulating system of FIG. 9 shows two amplifiers 64 and 65, each having a first and second amplifier input terminal, namely 66, 67 and 68, 69. The voltage U_n is supplied to the respective first amplifier input terminal 66 and 68 via input resistor 70 and 71, respectively. Terminal 66 further has a resistance 72, the eighth resistor, connected to the D.C. voltage source and a feedback resistor 73 connected with the output of the amplifier 64. The second amplifier input terminal 67 as well as the the second amplifier

input terminal 69 of the amplifier 64 and 65, respectively, is supplied with a constant voltage U_{E2} . A resistance 74 is connected between ground and terminal 68. This resistor is referred to as the ninth resistor herein. A feedback resistor 75 is connected from the amplifier output terminal of amplifier 65 to terminal 68. The output of D.C. amplifier 64 is connected to the anode of diode 76 whose cathode is connected to the fourth voltage divider terminal, namely the common terminal of resistors 85 and 86 which constitute fourth voltage divider means. The free terminals of resistors 85 and 86, respectively, are connected to the D.C. voltage source and ground. Resistance 86 here serves as a means for furnishing the desired speed signal, and the voltage across it serves to determine the quantity of fuel injected per cycle. It is a variable resistance. The output of amplifier 64 is connected to the fourth voltage divider terminal by means of a diode 76 whose anode is connected to the output of amplifier 64. The output of amplifier 64 is further connected to ground by way of the series combination of resistors 78 and 79 at whose common point is connected the cathode of a diode 80, whose anode is connected to the amplifier input 66 of amplifier 64. Correspondingly, the output of amplifier 65 is connected to the fourth voltage divider terminal through a diode 81 whose anode is connected to said fourth voltage divider terminal. The output of amplifier 65 is also connected to ground via series-connected resistors 82 and 83, at whose common point is connected the anode of a diode 84. The cathode of diode 84 is connected to the first input 68 of amplifier 65.

The operation of this arrangement is as follows. Amplifier 64 serves to generate both parts of the minimum speed limiting line. The location of the break in the line is determined by the values of resistors 78 and 79. The steeper part has an amplification equal to $V_R = -R73/R$ while the flatter portion has an amplification equal to :

$$V_R = R73 \parallel R78/R70.$$

The line may be moved in the horizontal direction by means of resistance 72. This serves to fix the minimum speed characteristic. Similarly the full-load matching line, as well as the maximum-speed limiting line are generated in the same fashion by means of amplifier 65. As in the operating region both by diodes 76 and 81 are blocked, and the output voltage U_v can be arbitrarily fixed by means of resistance 86 or an equivalent active element for generating a desired speed signal. The effective impedance of the voltage divider is to be so chosen that it is always large with respect to the output impedances of amplifiers 64 and 65.

A further embodiment of the second type of control system which operates only at the end characteristics is shown in FIG. 11. The corresponding characteristic lines are shown in FIG. 12. Here all lines are generated by means of a single direct current amplifier. Only the amplification of the amplifier is changed. Amplifier 87 has a first amplifier input 88 and a second amplifier input 89. A constant voltage U_{E2} is supplied to the second amplifier input, while the first amplifier input terminal is connected with the cathodes of two diodes 90 and 91. The anode of diode 90 is connected to feedback resistance 92, while the anode of diode 91 is con-

nected to a feedback resistance 93. These are referred to second and third feedback resistance, respectively. The free end of both the first and the second feedback resistance are connected to the anode of the diode 94 whose cathode is connected to the amplifier output terminal. The anode of diode 94 also constitutes the output terminal of the control system and the fuel control signal is derived between this terminal, terminal 95, and ground. The actual speed, namely voltage U_n , is connected via resistors 96 and 97 to the anodes of diodes 90 and 91, respectively. Furthermore, a resistance 98, the 12th resistor, is connected to the anode of diode 90. The other terminal of resistor 98 is connected to the D.C. voltage source. Further connected to the anode of diode 90 is the cathode of a diode 99 whose anode lies at the fixed voltage divider terminal, namely the common point of resistor 100 and 101. The free terminal of resistor 100 is also connected to the D.C. voltage source, while the free terminal of resistor 101 is connected to the anode of diode 94. Further connected to the amplifier output terminal is a voltage divider comprising a fixed resistance 103 in series with the variable resistance 104 whose free terminal is connected to the D.C. voltage source. Variable resistance 104 serves as the means for supplying the desired speed signal. At the common point of resistors 104 and 103 is connected a decoupling means, or an impedance changing network 105, which in turn is connected to the cathode of a diode 106 whose anode is connected to the anode of diode 91. Diode 106 is herein referred to as the tenth diode. A resistance 107 may be connected between the anode of diode 106 and the anode of diode 91 as indicated by the dashed lines. Output terminal 95 is connected to resistance 108 whose other terminal is connected to ground.

Operation of this system is as follows:

At the no-load region, diode 91 is conductive, while diode 90 disconnects the upper portion of the feedback network in FIG. 11 from the input terminal 88 of amplifier 87. The amplification of the minimum-speed limiting line V_{R2} is equal to

$$V_{R2} = -R93/R97.$$

Resistance 102 allows horizontal movement of the control line. With decreasing output voltage U_v , diode 106 becomes conductive at a point determined by resistance 104 (connected to the gas pedal). This causes, R_a , the output impedance of the impedance changer 105, which is very small compared to resistor 97 (for example an emitter-follower stage) to be inserted parallel to the resistance 93. The amplification then is

$$|V_{R4}| = R93 R_a/R97 \ll 1.$$

This results in the horizontal portion of the control lines. In some cases, it may be desirable to have a slight slope for the lines, such as V_{R4} in FIG. 12. This would be indicated by a line V'_{R4} shown in dashed lines in FIG. 12. The amplification $V_{R4} < 0$ required for this condition is achieved by insertion of resistor 107 shown in dashed lines in FIG. 11.

As the maximum speed is approached, diode 90 becomes conductive. The output voltage becomes more negative along the line labelled V_{R3} in FIG. 12 and blocks diode 91 via resistance 103, unit 105, diode 106, and possibly resistance 107. Amplification

$$V_{R3} = -R92/R96.$$

The position along the abscissa of the maximum-speed limiting line is determined by resistance 98 in conjunction with resistance 96. Resistance 96 is referred to as the tenth resistor, while resistance 98 is referred to as the twelfth resistor. If the output voltage U_v set by resistance 104 is greater than U_{v1} , then the transition from the characteristic of V_{R4} takes place first via a characteristic V_{R1} (full-load matching). For the transition to V_{R3} , diode 99 is conductive and the amplification is

$$V_{R1} = -R92 \parallel R101/R96.$$

The position of the V_{R1} line is relative to the abscissa determined by resistance 100. The maximum output voltage U_{vmax} is determined by the fifth voltage divider means comprising resistances 100, 101 and 108. The internal impedance of this voltage divider means must be smaller compared to resistance 92 and resistance 93.

FIG. 13 is an embodiment of a control system combining the two types of regulation. FIG. 14 shows the associated characteristic lines. In contrast to the types of regulators operating only in the extreme ranges of the region, the control lines are moved in the intermediate region also. The break in the characteristics occurs at a constant speed U_{n1} . In order to achieve this type of characteristic, the control system is constructed as follows:

A direct current amplifier 26 has a first amplifier input terminal 27 and a second amplifier input terminal 28. The cathodes of diodes 90 and 91 are both connected to terminal 27, while the anode of diode 90 is connected to a feedback resistance 92, and the anode of diode 91 is connected to the feedback resistance 93. The other terminals of the two feedback resistances are connected to the anode of diode 94, which also constitutes the output terminal 95 of the whole system. The cathode of diode 94 is connected to the amplifier output terminal 29. A constant voltage U_{E2} is supplied via a diode 120 to the second amplifier input 28. A resistance 119 is also connected to the anode of resistor 90, and has a second terminal connected to the D.C. voltage source. A resistor 115 interconnects the D.C. voltage source and the anode of diode 94. Further connected to the anode of diode 90 is a resistance 96, whose other terminal is connected to the input terminal 34 to which is applied the actual speed signal, namely voltage U_n . Further connected to the anode of diode 94 is a resistance 116, whose other terminal is connected to ground. Resistors 115 and 116 constitute seventh voltage divider means. The circuit comprising resistor 110, transistor 109, resistors 111, 113, 114 and diode 112 comprises means for effectively decreasing the resistance of the eleventh resistor for speeds exceeding the first predetermined speed. The first predetermined speed is U_{n1} . The circuit is constructed as follows:

Resistor 110 has one terminal connected to input terminal 34, and a second terminal connected to the emitter of transistor 109. The collector of transistor 109 is connected into the anode of diode 91. Transistor 109 has a base to which are connected the anode of diode 112 and one terminal of resistor 111. The other terminal of resistor 111 is connected to the D.C. voltage supply source, as is one terminal of resistor 113. The other terminal of resistor 113 is connected to the

cathode of diode 112 and also to one terminal of resistor 114, whose other terminal is connected to ground. The circuit of FIG. 13 further comprises a resistance 117 connected between the D.C. voltage source and ground, and having a wiper arm connected to resistance 118 whose other terminal is connected to the anode of diode 91. The circuit operates as follows:

In the no-load region, diode 90 is blocked and the upper part of the feedback network is decoupled from the amplifier. For $U_n < U_{n1}$, transistor 109 is conductive and the amplification is given by the value

$$V_{R1} = -R93/R97 \parallel R110.$$

The break point, determined by U_{n1} is determined by the values of resistors 113 and 114. When transistor 109 blocks at a voltage U_n approximately equal to U_{n1} , the resistance 97 determines the slope of the control line (V_{R2}). Displacement of the line takes place as a function of the variable current furnished by the gas pedal via the resistance 118. (Resistance 118 may also be connected to an active element for generating a desired speed signal). At a voltage U_{n2} , determined by resistance 119, diode 90 becomes conductive. The maximum-speed limiting line takes place. Because of the increasingly negative potential U_v , diode 91 becomes blocked and the lower part of the feedback network is removed from the amplifier.

The slope of the maximum-speed limiting line is given by

$$V_{R3} = -R92/R96.$$

Variations with temperature of the break-down voltage of diode 90 and 91 may be compensated for by a diode 120 connected to the second amplifier input.

The value of resistances 92 and 93 is chosen to be sufficiently large that for a blocked diode 112 the direct influence of U_n onto the output voltage divider may be neglected.

FIG. 15 shows an embodiment and FIG. 16 the associated characteristic lines of a control system of the first type wherein the break in the control line characteristic does not take place at a constant speed. The point at which the break occurs is referred here as the changeover speed. One might say that in this case, as the control lines are moved in the direction of the abscissa, the break point is moved in the direction of the ordinate. Thus, the break point moves along a substantially straight line having a determined angle with the abscissa. The relatively flatter portion of the control line associated with the no-load region, namely the portion labelled V_{R2} tends to vanish as the line is displaced towards the maximum-speed control line, while the relatively steeper portion corresponding to an amplification V_{R1} becomes more and more effective. The circuit is constructed as follows:

Connected to the first amplifier input terminal 27 of direct current amplifier 26, are resistances 121, 122, 124 and 125, the anode of a Zener diode 123, and the collector of an npn transistor 126 which constitutes switching means. Resistance 121 (input resistor) has its second terminal connected with the input terminal 34. The voltage corresponding to the desired speed value is applied at the speed terminal 138 to which is connected the second end of resistor 124 which, with resistance 125, forms eighth voltage di-

vider means. The free end of resistor 125 is connected to the D.C. voltage source, while resistance 122 is connected to the output voltage divider comprising resistances 127 and 128. Further connected to the output voltage divider terminal, which also constitutes the output terminal 95 of the whole system and is the common point of resistors 127 and 128, is the anode of a diode 94 (eight diode), whose cathode is connected to the amplifier output terminal 29. The cathode of Zener diode 123 is connected to the cathode of a diode 129 whose anode is directly connected to the amplifier output terminal 29. The base of transistor 126 is connected on the one hand to resistor 130 whose other terminal is connected to the D.C. voltage supply source; and on the other hand, to the anode of a diode 131, whose cathode is connected to the ninth voltage divider terminal, namely the common point of resistors 132 and 133 constituting the ninth divider means. The clamping diode 134 is connected to the emitter of transistor 126 and to the ninth voltage divider terminal. Resistors 135, 136 (additional input resistance), and 137 (sixteenth resistor) are also connected to the emitter of transistor 126. The other terminal of resistance 135 is connected to ground and that of resistance 136 to the input terminal 34, while the other terminal of resistance 137 is connected to the output voltage divider terminal 95. A constant voltage U_{E2} is connected to the second input terminal 28 of amplifier 26. Operation of this circuit is as follows:

For the steep portion of the control line, transistor 126 is blocked, the amplification is then

$V_{R1} = -R_{122}/R_{121}$ as long as Zener diode 123 is blocked. The current introduced via resistance 124 to the input terminal 27 effects the horizontal displacement of the control line. The extreme values of displacement region for a given voltage variation may be determined by resistances 124 and 125.

At the break in the characteristic, transistor 126 becomes conductive, and the lower part of the feedback network comprising transistor 126, resistors 130, 132, 133, 135, 136 and 137, as well as diodes 131 and 134, becomes effective. A voltage U_T is developed across the resistance 133 and applied to the base of transistor 126 via diode 131. Diode 131, whose anode is connected to the base of transistor 126 serves for temperature compensation. The voltage U_T is so chosen that a sufficient collector-emitter voltage U_{CE} is available for operation of transistor 126 in the active region ($U_I < U_{E2}$).

The amplification of the lower part of the control line then is determined by the ratio of the total feedback resistance (with transistor 126 conductive) to the total input resistance namely:

$$-\frac{R_F}{R_E} \text{ where } R_F = R_{122} \parallel \frac{R_{137}}{A_N} = \frac{R_{122} \cdot R_{137}}{A_N \cdot R_{122} + R_{137}}$$

and

$$R_E = R_{121} \parallel \frac{R_{136}}{A_N} = \frac{R_{121} \cdot R_{136}}{A_N \cdot R_{121} + R_{136}}$$

yielding:

$$V_{R2} = -R_F/R_{121} + R_F/R_{136} \cdot A_N,$$

wherein A_N stands for the current amplification of transistor 126 in a common base connection. As the input voltage U_n increases, the switch-in voltage (approximately U_T) at the emitter of transistor 126 is reached for ever decreasing values of output voltage.

The break point is moved along a line having a slope

$V_K = -R_{137}/R_{136}$, whose position in the characteristic field may be changed without a change in slope by changing the value of resistor 135. This resistor changes the voltage at the emitter of transistor 126, as is evident by reference to FIG. 15, thereby changing the voltage at input terminal 27 of amplifier 26.

If the output voltage of the amplifier at terminal 29 exceeds the voltage at the common point of resistors 127 and 128, then, diode 94 blocks, and the feedback circuit is completed over Zener diode 123 and diode 129, i.e. feedback resistors 122 and 137 are shortcircuited.

Thus the input terminal 27 remains at a constant potential U_{E2} , and a direct effect on the output voltage of U_n , or, respectively, the desired speed signal (terminal 138), via resistance 122, is prevented.

In the lower part of the feedback circuit, the clamping diode 134 serves the same function as does Zener diode 123 in the above-described operation of amplifier 26. As soon as the voltage U_n exceeds the voltage U_T across resistor 133, transistor 126 blocks and clamping diode 134 conducts. This causes the common point of resistors 136 and 137 to remain at voltage U_T , effectively preventing changes in U_n from influencing U_n . In order to maintain a constant voltage or a substantially constant voltage across resistance 133, the individual resistances of resistors R_{137} , R_{136} must be much greater than the resistance of R_{132} in parallel with R_{133} .

It has thus been shown by use of a number of embodiments, that any type of desired control characteristics may be achieved only by varying the feedback circuit or the input circuit of a direct current amplifier having a sufficiently high amplification. The position and the slope of individual control lines or control line portions may be changed within wide regions independent of one another. The desired speed signal may be furnished by active or by passive means. The time constants of such control systems is generally negligible compared to the other time constants appearing in the system. The phase shift of the control system is zero in the frequency region concerned. It is of course also possible to change the amplified characteristics fixed to either a differentiating or integrating type of characteristic by adding the active component to the resistive components in the feedback circuits.

While the invention has been illustrated and described as embodied in input and feedback circuit configurations, it is not intended to be limited to the details shown, since various modifications and circuit changes may be made without departing in any way from the spirit of the present invention.

What is claimed as new and desired to be protected by Letters Patent is set forth in the appended claims:

1. Control system for internal combustion engine, comprising, in combination, at least one fuel control means furnishing fuel to said engine throughout an operating range comprising minimum and maximum speeds and minimum and maximum fuel supply, in dependence upon a fuel control signal; means for furnishing a desired speed signal corresponding to the desired engine speed; means for furnishing an actual speed signal corresponding to the actual engine speed; and high gain direct current differential amplifier means connected to said means for furnishing a desired speed

signal and said means for furnishing an actual speed signal, said high gain direct current differential amplifier means having a first and second amplifier input terminal, an amplifier output terminal, a first and second amplifier input circuit respectively connected to said first and second amplifier input terminal, and a feedback circuit connected between said amplifier output terminal and said first input terminal, said high gain direct current differential amplifier means furnishing said control signal within said operating range in response to the difference between signals applied respectively at said first and second amplifier input terminal, said first amplifier input circuit or said feedback circuit including at least one impedance changing element for changing the impedance thereof in response to signals generated in said high gain direct current differential amplifier means under predetermined operating conditions of said internal combustion engine, whereby said control signal varies also as a function of the impedance of said impedance changing element.

2. A control system as set forth in claim 1, wherein said control system is adapted to maintain a constant engine speed, independent of load changes.

3. A control system as set forth in claim 1, wherein said control system is adapted to maintain the lowest no-load speed above a predetermined minimum no-load speed, and to limit the top no-load speed to a predetermined maximum no-load speed.

4. A control system as set forth in claim 2, wherein said speed control system is further adapted to maintain the lowest no-load speed above a predetermined minimum no-load speed, and to limit the top no-load speed to a predetermined maximum no-load speed.

5. A control system as set forth in claim 2, wherein said feedback circuit comprises only passive electrical component.

6. A control system as set forth in claim 5, wherein said first amplifier input circuit has a first input terminal; wherein said actual speed signal is applied to said first input terminal; further comprising a first resistor connecting said first input terminal to said first amplifier input terminal.

7. A control system as set forth in claim 6, wherein a constant input voltage is applied at said second amplifier input terminal.

8. A control system as set forth in claim 7, wherein said means for furnishing a desired speed signal comprise a passive electrical component having a variable characteristic.

9. A control system as set forth in claim 8, wherein said passive electrical component comprise in said means for furnishing a desired speed signal is a variable resistance; and wherein said variable resistance is connected in series with a fixed resistance, the series circuit comprising the said resistances being connected to said first input terminal.

10. A control system as set forth in claim 9, further comprising a D.C. voltage source; and wherein said series circuit has a terminal connected to said D.C. voltage source.

11. A control system as set forth in claim 10, further comprising a first diode having an anode connected to said series circuit and a cathode connected to said first amplifier input terminal.

12. A control system as set forth in claim 9, wherein said feedback circuit comprises a single feedback resistance; wherein said D.C. amplifier has amplifier output terminals; and wherein said feedback resistance is connected from said amplifier output terminal to said first amplifier input terminal.

13. A control system as set forth in claim 12, further comprising first voltage divider means connected from said D.C. voltage source to ground, and having a voltage divider terminal; and second diode means having an cathode connected to said amplifier output terminal and an anode connected to said voltage divider terminal.

14. A control system as set forth in claim 13, wherein said feedback circuit comprises a feedback resistance having a first terminal connected to said first amplifier input terminal and a second terminal connected to the anode of said second diode; and wherein said fuel control signal is derived from the anode of said second diode.

15. A control system as set forth in claim 11, further comprising a fifth resistor connected between the cathode of said first diode and said first amplifier input terminal.

16. A control system as set forth in claim 15, further comprising third voltage divider means connected from the anode of said second diode to said D.C. voltage source, said third voltage divider means having a third voltage divider terminal; and third diode means having an anode connected to said first amplifier input terminal and a cathode connected to said third voltage divider terminal.

17. A control system as set forth in claim 16, further comprising a fifth resistor connected between said third voltage divider terminal and said input terminal.

18. A control system as set forth in claim 17, further comprising means for preventing amplifier overdrive connected between said amplifier output terminal and said first amplifier input terminal.

19. A control system as set forth in claim 18, further comprising a seventh resistor connected between the anode of said second diode and said input terminal.

20. A control system as set forth in claim 3, wherein said high gain direct current differential amplifier means comprise a first and second direct current amplifier respectively having a first and second input circuit and a first and second feedback circuit, said first direct current amplifier having a first and second first amplifier input terminal, said second direct current amplifier having a first and second second amplifier input terminal, said first direct current amplifier having a first amplifier output terminal, said second direct current amplifier having a second amplifier output terminal; wherein said first and second input circuits have a common input terminal; and wherein said actual speed signal comprise an actual speed voltage connected to said common input terminal.

21. A control system as set forth in claim 20, wherein a constant voltage is applied to the second amplifier input terminal of said first and second direct current amplifiers.

22. A control system as set forth in claim 21, further comprising a D.C. voltage source; fourth voltage divider means connected across said D.C. voltage source, and having a fourth voltage divider terminal; a fourth diode connected between said fourth voltage divider

terminal and said first amplifier output terminal; and a fifth diode connected between said fourth voltage divider terminal and said second amplifier output signal.

23. A control system as set forth in claim 22, wherein said pure control signal is derived from said fourth voltage divider terminal, said variable resistance constituting said means for furnishing a desired speed signal.

24. A control system as set forth in claim 22, wherein said fourth voltage divider means comprise a fixed resistance connected from said D.C. voltage source to said fourth voltage divider terminal; and wherein said means for furnishing a desired speed signal comprise a current source connected from said fourth voltage divider terminal to ground.

25. A control system as set forth in claim 23, further comprising an eighth and ninth resistor respectively connected from said first first amplifier input terminal and said first second amplifier input terminal to ground.

26. A control system as set forth in claim 24, further comprising an eighth and ninth resistor respectively connected from said first first amplifier input terminal and said first second amplifier input terminal to ground.

27. A control system as set forth in claim 20, wherein said first and second feedback circuit each comprise a resistance-diode combination.

28. A control system as set forth in claim 4, wherein said feedback circuit comprises a first feedback circuit and a second feedback circuit, and wherein said first feedback circuit or said second feedback circuit become effective as a function of the speed of said internal combustion engine.

29. A control system as set forth in claim 28, wherein said first feedback circuit is effective in the no-load region; and wherein said second feedback circuit is effective following the no-load region until the maximum permissible speed is attained.

30. A control system as set forth in claim 29, wherein said input circuit has an input terminal; wherein said input circuit comprises a tenth and eleventh resistor, each having a first terminal connected to said input terminal, each having a second terminal; and sixth and seventh diodes, respectively having an anode connected to the second terminal of said tenth and eleventh resistors, and a cathode connected to said amplifier input terminal.

31. A control system as set forth in claim 30, further comprising an eighth diode having a cathode connected to said amplifier output terminal and an anode; and second and third feedback resistances connected from the anode of said eighth diode to the second terminal of said tenth and eleventh resistor, respectively.

32. A control system as set forth in claim 31, further comprising a twelfth resistor connected from said D.C. voltage source to the anode of said sixth diode; a fifth voltage divider means having a fifth voltage divider terminal connected from said D.C. voltage source to the anode of said eighth diode; and a ninth diode connected from said fifth voltage divider terminal to the anode of said sixth diode.

33. A control system as set forth in claim 32, wherein said means for furnishing a desired speed signal comprise a variable resistance having a first terminal connected to said D.C. supply source and a second ter-

minal; and fixed resistance means interconnecting said second terminal of said variable resistance and said amplifier output terminal.

34. A control system as set forth in claim 33, further comprising decoupling means connected to the second terminal of said variable resistance; a tenth diode having a cathode connected to the output of said decoupling means and an anode; and a thirteenth resistor, interconnecting the anode of said tenth diode and said D.C. voltage source.

35. A control system as set forth in claim 30, further comprising means for effectively decreasing the resistance of said eleventh resistor for speeds exceeding a first predetermined speed.

36. A control system as set forth in claim 35, wherein said means for effectively decreasing the resistance of said eleventh resistor comprise a fourteenth resistor having a first terminal connected to said input terminal, and a second terminal; and an electronic switching means adapted to connect said second terminal of said fourteenth resistor to the corresponding terminal of said eleventh resistor when the speed of said internal combustion engine exceeds said first predetermined speed.

37. A control system as set forth in claim 36, wherein said electronic switching means comprise a first transistor having an emitter connected to said fourteenth resistor, a collector connected to said eleventh resistor, and a gate.

38. A control system as set forth in claim 37, further comprising a gate circuit for furnishing a voltage to the gate of said transistor.

39. A control system as set forth in claim 38, wherein said gate circuit comprises sixth voltage divider means connected between said D.C. voltage source and ground and having a sixth voltage divider terminal; a fifteenth resistor connected from said D.C. voltage source to the gate of said transistor; and diode means interconnecting said gate and said sixth voltage divider terminal.

40. A control system as set forth in claim 39, wherein said means for furnishing a desired speed signal comprise means for furnishing a current proportional to said desired speed to the common point of said eleventh resistor and said seventh diode.

41. A control system as set forth in claim 40, further comprising seventh voltage divider means connected between said D.C. voltage source and ground and having a seventh voltage terminal, said seventh voltage divider terminal being connected to the anode of said eighth diode.

42. A control system as set forth in claim 41, wherein a constant input voltage is supplied to the second amplifier input terminal.

43. A control system as set forth in claim 4, wherein said feedback circuit comprises a first feedback circuit and a second feedback circuit; wherein said second feedback circuit becomes effective after the speed of said engine exceeds a changeover speed; and wherein said changeover speed varies in dependence upon the fuel-speed control characteristic along which said combustion engine is being operated.

44. A control system as set forth in claim 43, wherein said input circuit comprises an input resistor having a first terminal constituting an input terminal and a

second terminal connected to said first amplifier input terminal; an eighth diode having a cathode connected to said amplifier output terminal and an anode; wherein said first feedback circuit comprises a resistance connected between the anode of said eighth diode and said first amplifier input terminal; wherein said second feedback circuit comprises a 16th resistor having a first terminal connected to the anode of said eighth diode and a second terminal; electronic switching means for connecting said second terminal of said sixteenth resistor to said first amplifier input terminal when the speed of the engine exceeds said changeover speed; and an additional input resistance having a first terminal connected to said input terminal and a second terminal connected to the second terminal of said 16th resistor.

45. A control system as set forth in claim 44, further comprising an additional feedback circuit including a Zener diode connected between said amplifier output terminal and first said amplifier input terminal.

46. A control system as set forth in claim 45, wherein a constant voltage is applied to said second amplifier input terminal.

47. A control system as set forth in claim 46, further comprising a D.C. voltage source; and output voltage divider means having an output voltage divider terminal connected from said D.C. voltage source to ground, said output voltage divider terminal being connected to the anode of said eighth diode.

48. A control system as set forth in claim 47, wherein said means for furnishing a desired speed signal comprises means for furnishing a voltage proportional to said desired speed at a speed terminal; eighth voltage divider means connected between said speed terminal and said D.C. voltage source, and having an eighth voltage divider terminal connected to said first amplifier input terminal.

49. A control system as set forth in claim 48, wherein said electronic switching means comprise a transistor having a base and an emitter-collector circuit, said emitter-collector circuit connecting said 16th resistor to said first amplifier input terminal when said transistor is conductive.

50. A control system as set forth in claim 49, further comprising ninth voltage divider means connected between said D.C. voltage source and ground, and having a ninth voltage divider terminal; a temperature compensating diode connected between the base of said transistor and said ninth voltage divider terminal; a clamping diode connected between the emitter of said transistor and said ninth voltage divider terminal; a resistor connected between said D.C. voltage source and said base; a resistor connected between said emitter and ground; and a resistor connected between the cathode of said clamping diode and ground.

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