July 19, 1949. D. C. COX 2,476,534

VOLTAGE OR CURRENT REGULATOR

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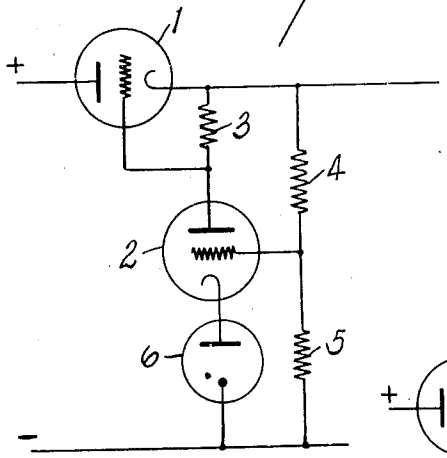
Fig. 1 (PRIOR ART)



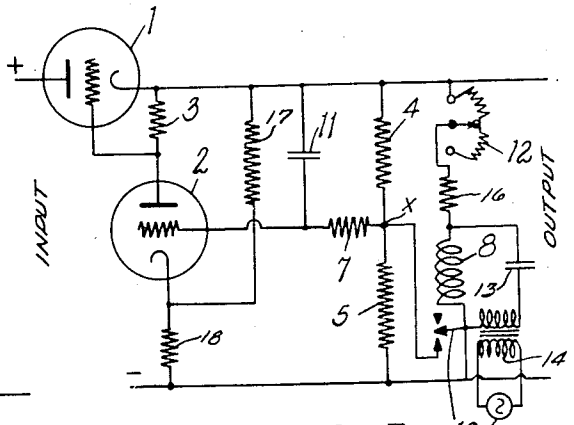


Fig. 3.

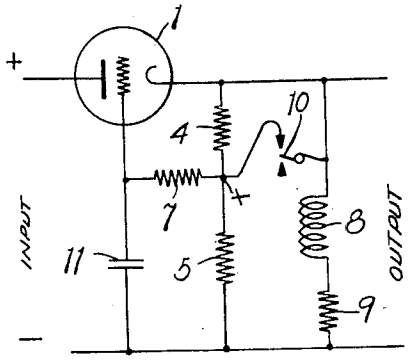


Fig. 2.

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VOLTAGE OR CURRENT REGULATOR

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This invention relates to improvements in voltage or current regulators.

The main objects of this invention are:

First, to provide an improved comparison, reference or standard device for a voltage or current regulator of the thermionic type, adapted to replace the conventional reference sources of the orthodox regulator, with great improvement in the operation of the regulator.

Second, to provide a reference, comparison or standard circuit or device for a regulator of the type described which is completely free from the effects which have rendered previous comparison standards in regulators unreliable, viz., variations due to temperature change, age or voltage drop.

Third, to provide a device of the type described in which all components thereof, such as tubes, resistors, etc., may be replaced, interchanged or altered without appreciable effect on the operation of the device in the regulator.

Fourth, to provide an electronic regulator of the type described having a novel and improved standard or comparison circuit, which is of a very simple and inexpensive nature.

Fifth, to provide an improved regulator and standard device therefor, of the type referred to above, wherein means are provided to perform exceedingly rapid comparisons and corrections or adjustments, with resultant refinement of the smoothness of the regulated output, as well as improvement in the mechanical operation of the device concerned.

In the drawings, wherein like reference characters are employed to designate corresponding parts,

Fig. 1 is a wiring diagram illustrating a conventional type thermionic voltage regulator, including a reference or standard voltage source upon which the action of the regulator is predicated and which will be supplanted by the improved reference circuit according to my invention.

Fig. 2 is a wiring diagram illustrating a fundamental and extremely simple regulator embodying the improved reference structure of the invention.

Fig. 3 is a wiring diagram illustrating a generally similar circuit provided with an additional stage of amplification and with certain additional devices to further improve the operation of the regulator.

Referring to Fig. 1, wherein I have illustrated an entirely orthodox voltage regulator of the thermionic type, the details and operation of this structure are so well known as to require no extended explanation. A regulating or gate tube 1 on whose plate the potential to be regulated is impressed, has the grid thereof biased by the plate voltage of an amplifier 2, whose plate resistor is designated 3. The grid of this amplifier is connected to a point of known potential on the voltage divider 4, 5, and the filament is supplied by a source of relatively constant potential 6, such as a standard VR tube, battery or neon lamps. This mode of connection of the grid and filament of the amplifier is intended to make the same subject to a standard comparison or reference condition, so that by comparing the output voltage of the regulator therewith the amplifier will be caused to impose more or less bias on the grid of the gate tube 1, when a variation in the voltage on the system occurs, and thereby make an instantaneous correction in the proper direction.

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Though this orthodox arrangement functions well enough for ordinary work, it is subject to certain disadvantages which cannot be tolerated in a regulator required to operate for substantial periods with high efficiency and smoothness of output. For example, a gaseous VR tube when employed as a standard 6 gives only an approximation of a constant reference voltage, for variations of 1% to 2% in voltage drop across such tubes are customary. A battery will also vary with age and temperature. Likewise, the warming of the resistors will cause a drift in output during the warm up period, and change in ambient temperature will affect the VR tube and all resistors, unless special expensive alloys are used. Moreover, if any given element, either tube or resistor, is replaced or altered a change in the output will occur. Thus the output may vary considerably if amplifier 2 is replaced by a similar but not identical tube.

By the present invention I have provided a reference and control circuit for a regulator wherein all the above drawbacks are eliminated and, moreover, one by which the output constancy of the regulator is strikingly improved.

Reference should first be made to Fig. 2, illustrating a very elemental form of regulator embodying the principle of the present invention. Here the gate tube 1 is unassisted by an amplifier, its grid being connected through resistor 7 to the midpoint X of voltage divider 4, 5, to provide a suitable negative bias for tube 1 representing the cut-off condition. A contacting voltmeter, or voltmeter-relay, generally designated 8, provided with a filler resistor 9, is connected to read the output voltage. Said voltmeter has a contact arm 10 serving as a sensitive relay contactor

adapted to contact one of two contacts, as shown. When the output drops too low the arm makes a contact (which may be designated the "low" contact), shorting out resistor 4 of the voltage divider and providing zero bias for the gate tube grid, which causes that tube to open wide. Otherwise the arm disengages the "low" contact and the high bias is effective.

Without further structure, the above device could hardly qualify as a regulator, for the output voltage would jump vigorously from very high to very low. The element completing the structure is a feedback condenser 11 connecting the gate grid to the negative output line. When the "low" contact is made, the junction point of resistors 4, 5 comes up to positive output potential. The tube would be at zero bias if this voltage succeeded in getting to the gate grid. However, as current starts to flow through resistor 7 the negative line jumps downward slightly in potential and this jump is transferred through the condenser, holding the grid to almost the same position as it was before the contact was made. The condenser is unable to hold the grid biased for very long, because actual current flows through resistor 7 and into the condenser, the latter slowly takes on a charge and the negative line slowly moves in a downward direction, eventually obtaining enough voltage to pull the voltmeter arm 10 off the "low" contact. Thereupon a high bias again starts to flow to the grid, but is again impeded by the action of the condenser, which does not stop it but restrains it. The result is that a gentle V-wave output is obtained. The slope of the sides of the V is determined by the capacity of the condenser and the size of the resistor. By choosing high values for resistor 7 and the condenser, a very low slope, appearing almost as a straight line, may be secured.

With different resistors and/or a different gate tube substituted for the original installation, the time at which the voltmeter releases contact may vary, hence the time at which a rise in slope ends, but it will always occur at the same voltage point. Thus the final average output voltage is unaffected by variations in the characteristics of a given installation of resistors and tube; the final average output voltage is determined solely by the contacting voltmeter.

In Fig. 3 I illustrate the contacting voltmeter concept applied to a regulator having a stage of amplification in addition to the gate tube 1. Here it will be noted that the grid of amplifier 2 is connected through feedback condenser 11 to the positive output line rather than the negative, as in the one-stage-of-amplification regulator of Fig. 2, and it is resistor 5 which is shorted out by the voltmeter. The arrangement of the voltmeter 8 and its resistor is also reversed, and furthermore the resistor in this case is a special type, designated 12, as will be explained. The rule governing the connection of the feedback condenser calls for its connection to negative when an odd number of stages of amplification are used, counting the gate tube as a stage, and to positive when an even number of stages are employed in cascade.

The reference numeral 12 designates a selective resistor, such as of the decade type, which is manually settable for any desired resistance, instead of the fixed resistor 9 shown in Fig. 2. I thereby enable the control voltage on the contacting voltmeter to be set at the appropriate desired value to bring the latter into operation. A fixed resistor 16 is connected in series with the

variable resistor 12. Resistors 17 and 18 form a voltage divider providing the desired voltage for the cathode of the amplifier tube 2.

The operation of the Fig. 3 regulator is in all respects comparable to that in Fig. 1, but with improved smoothness of output and flexibility. The grid of amplifier 2, at which the control of the regulator is introduced, has two controls. One is the signal through resistor 12 and the contacting voltmeter 8, which determines the final output of the regulator regardless of other elements of the circuit. In other words, the voltmeter determines the boundary conditions of voltage output.

To do this the voltmeter from time to time corrects the charge of the feedback condenser 11, which is the second control. This condenser assumes a certain charge after it has been operating, which charge may be considered normal. It then functions as a source of reference voltage to offset surges in the line from the power source, by appropriately biasing the grid of gate tube 1. Since no condenser will maintain a charge indefinitely, it is necessary to correct the charge from time to time to offset normal leakage in the condenser and amplifier grid circuits. This is the function of contacting voltmeter 8. But otherwise this capacitor functions without assistance from the voltmeter to remove transients or hum by a factor equal to the effective gain of the amplification system. The contacting voltmeter is given sufficient control to determine the final output and thereafter maintains exactly the correct charge on the condenser.

It will appear from the foregoing that in order to obtain the smoothest possible output and avoid V-wave in the output, it is highly desirable to cause the contacting voltmeter to make its contacts rapidly. This might be done by mechanically vibrating the contact point of the voltmeter-relay at suitably high frequency. However, I prefer to do it by introducing an A. C. ripple into the coil of the voltmeter.

Referring to Fig. 3, it will be noted that I have shown a condenser 13, between the plus terminal of the contacting voltmeter coil and a suitable source of A. C. voltage. The secondary of transformer 14, the primary of which may be supplied from any appropriate source of alternating current 15, will serve to supply the alternating current. The function of this condenser connection is to so excite the meter winding as to produce a very slight vibration of the meter contacting arm 10 over an extremely small angular distance at a frequency equal to the line frequency, for example, 60 vibrations per second. This is ordinarily sufficient to eliminate all perceptible V-wave from the output.

A meter operating on an exceedingly quiet current and prevented from receiving even slight mechanical vibration, is under starting friction at all times and as a result appears to be inferior in its response, sometimes having considerable lag. By the above provisions I convert the standing friction effective on said arm to running friction, and thereby in reality make the meter produce 60 corrections per second. The importance of this improvement, simple though it may seem, is readily apparent when the output is observed on an oscilloscope, with and without excitation of the meter coil.

It will be appreciated from the foregoing that I have provided a standard for a regulator which reveals if the output is in error and which alters the amplifier bias to correct the error, which

standard is subject to none of the deficiencies of previous standards, as pointed out in detail above. Timing of the updrift and downdrift circuits set up in the operation of the device may be readily regulated by varying the condenser and bleeder resistors. Resistor 7 is very important in this regard. The output voltage may be adjusted in accurate steps by switching in of resistance at resistor 12 in the voltmeter line.

Any good contacting voltmeter arrangement of the type described is preferable as a reference standard to a VR tube or battery, as examples of conventional expedients, for even with a theoretically perfect VR tube or battery perfect regulation is not assured, inasmuch as an amplifier with finite gain will not copy accurately. The filaments or heaters of amplifiers, particularly the first stage, cause shifting of bias when heater voltage changes. Since the sensitive relay constituted by the contacting voltmeter 8 may be shown to have large amplification characteristics, it follows that I have provided what is in effect a first amplifier, which is free from this heater error, having no heater. Moreover, since the output voltage is established by the contacting voltmeter, it is not significantly influenced by the amplifier tubes. Hence these may change due to age or be exchanged for other tubes without perceptibly altering the output voltage. If a new set of tubes in a high gain amplification system has four times the gain of the old ones, the output ripple will be lower but the average voltage will be the same.

I have previously referred to the fact that the contacting voltmeter makes the "low" contact in order to bring into effect the means for applying a corrective grid bias. I have found that, due to the sensitivity of the device in resisting any voltage change in the output, considerable time elapses before the regulator rises to the desired operating level after starting. That is, the rise in voltage incident to starting of operation is opposed with about the same effectiveness as are the changes in voltage when the operative range of the regulator has been reached. Hence I contemplate that the contacting voltmeter connections may be reversed so that arm 10 engages the opposite contact during starting conditions. By employing a suitable manual switch a resistor of much smaller value than resistor 4 of Fig. 2 or resistor 5 of Fig. 3, say 2 ohms as compared to 1000, can be caused to be cut in when the voltmeter makes said opposite or "high" contact. This enables high speed action of the regulator in reaching its operative level. I desire that this concept be included in any interpretation of the appended claims.

The present development provides a regulator standard in which the charge on a feedback capacitor serves as a reference and makes instantaneous regulation to reduce ripple in the output, and in which any inconstancy in this charge caused by normal leakage in the capacitor and grid circuits is offset by frequent minute corrections instituted by the contacting voltmeter. These elements operate as a combination to effectively eliminate all the previous drawbacks of corresponding reference devices. Their action is improved and refined by the introduction of a slight A. C. component by a condenser in the voltmeter circuit, or by any other equivalent means for preventing lag in the reaction of the meter arm and for breaking up its response into many frequent movements. In effect, what happens in this feedback type standard is that transient variations in the signal coming from the contacting voltmeter are subjected to great filter action and fed back to the amplifier grid in proper phase to oppose the changes. It will regulate the voltage within .06 of 1%, this effectiveness not being subject to diminution by any of the above discussed variable factors which have previously entered into the operation of similar type regulators.

In the circuit above described, no attempt has been made to illustrate the power supply being regulated. It may indeed be any desired source subject to variations which cannot be tolerated at the load. It may come from a rectifier pack, a D. C. generator, or the like, in fact any voltage high enough to provide the desired output voltage, plus the gate voltage.

Though I have illustrated the invention as applied to a voltage regulator, it is to be clearly understood that the improved provisions are equally applicable to a current regulator. As the terms are used herein a voltage regulator is a device for maintaining constant voltage across a load. The voltage sample is obtained from part of a resistance voltage divider spanning the load terminals. The voltage sample is proportional to the output voltage. A current regulator is devised to maintain a constant voltage across a resistor located in series with the load. The voltage sample is proportional to the output current. Thus both devices are voltage regulators but since they maintain constant voltage at entirely different parts of the circuit they obtain almost diametrically opposite results.

With a constant load such as that furnished by a fixed resistor the two types of regulator show identical behavior at the output delivering constant wattage to the load, the one by fixing the voltage, the other by fixing the amperage, the other factor being fixed in accordance with Ohm's law. Thus, with fixed load and variable line voltage almost identical behavior is had from the two regulators and is in fact obtained with almost identical structure and function.

In the presence of a varying load resistance the two behave quite differently. Upon doubling the load resistor a voltage regulator maintains the voltage constant, causing the current to drop to one-half its original value. The wattage delivered to the load is halved. On the other hand upon doubling the load resistor a current regulator will maintain the current, developing double the voltage to accomplish this and will deliver twice the wattage to the load. A voltage regulator idles if the load be removed. Here the watts or volt-amperes are zero because the amperes are zero. A current regulator idles if the load terminals be short-circuited. Here the volt-amperes are zero because the volts are zero.

Thus it will appear that adoption of the principle of the invention in a current regulator is a matter well within the scope of one skilled in the art.

I have described embodiments of the invention which I believe will enable those skilled in the art to embody or adapt the invention as may be desired. I have not illustrated or described other embodiments and modifications which I contemplate, as it is believed this disclosure will readily enable the adaptation of the invention, and I desire to claim the same specifically as well as broadly within the scope of the appended claims.

Having thus described my invention, what I claim as new and desire to secure by Letters Patent is:

1. In a regulator of the type described, a control element connected to a power source to regulate the output thereof and having a control grid, and a standard device connected across the output of said regulator and subject to variations therein, said device comprising a relay making contact in response to the output voltage and variations therein, a resistor in circuit with said grid and alternately connected to the output circuit or shorted out by said relay, and a feedback capacitor controlled by said relay connected to the grid and in series with said resistor across the output circuit, and subject to change in charge when said shorting occurs, thereby variably biasing said grid in a manner to oppose and offset the variations.

2. In a regulator of the type described, a control element connected to a power source to regulate the output thereof and having a control grid, and a standard device connected to the output of said regulator and subject to variations therein, said device comprising a relay making contact in response to the output voltage variations, a resistor in circuit with said grid and controlled by said relay whereby to be shorted out in response to the contact made by said relay, and a feedback capacitor controlled by said relay connected to the grid and in series with said resistor, said condenser being subject to change in charge when said shorting occurs, thereby variably biasing said grid in a manner to oppose and offset the variations.

3. In a regulator of the type described, a control element connected to a power source to regulate the output thereof and having a control grid, and a standard device connected to the output of the regulator and subject to variations therein, said device comprising a relay making contact in response to the output voltage variations, and a feedback capacitor controlled by said relay connected to the grid and subject to change in charge by connection across the output of the regulator in accordance with the making of said contact, thereby variably biasing said grid in a manner to oppose and offset the variations.

4. In a regulator of the type described, in combination with a grid controlled thermionic tube connected to vary the impedance of an output line, a standard device controlling the action of said tube, comprising a capacitor connected to the grid of said tube and one side of said output line, said capacitor being effective on said grid to bias the same, a sensitive relay connected to the output line and capacitor to control charging of the latter in response to said output line variations by connecting said capacitor across said line, and means for subdividing the action of sail relay into a multiplicity of governing actions of small amplitude and high frequency.

5. In a regulator of the type described, in combination with a grid controlled thermionic tube connected to vary the impedance of a circuit to be regulated, a capacitor connected to the grid of said tube and across said circuit, and subject to changes in charge as a result of variations in the latter, which changes are effective on said grid to bias the same, means connected to the circuit and responsive to the voltage therein to define the limit of the charge of said capacitor, and means for subdividing the action of said first-named means into a multiplicity of governing actions of small amplitude and high frequency.

6. A standard for a regulator of the type described having an electronic tube functioning in the regulation of the flow of current from an input source to an output line, said standard comprising a resistor and a capacitor connected in series across said line and adapted to impose a predetermined charge on said tube to control the same, means including a relay controlled by the output line to determine the extent of said charge by shorting said resistor, said relay having coacting relatively fixed and movable elements, and means for producing a slight relatively high frequency vibration of said elements superimposed on the normal make and break movement thereof.

7. A standard for a regulator of the type described having an electronic tube functioning in the regulation of the flow of current from an input source to an output line, said standard including a capacitor connected across the output line and connected to and adapted to impose a predetermined charge on said tube to control the same, and means including a relay connected to and controlled by the output line to determine the extent of said charge.

8. In a regulator of the type described, the combination of an electronic tube functioning in the regulation of the flow of current from an input source to an output line, a grid controlled thermionic tube arranged to control said electronic tube, a voltage divider connected to said output line and arranged to provide bias for said thermionic tube, a capacitor connected in a parallel with one portion of said divider, and a contacting voltage meter in circuit with said output line and arranged to make and break a contact in response to variations in said line, the making of said contact being arranged to short out the other portion of said voltage divider.

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