

PATENT SPECIFICATION

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(54) CONTROLLER DEVICES

(71) We, YOKOGAWA ELECTRIC WORKS, LTD. a Japanese Company, of 2-9 Nakacho, Musashino-shi, Tokyo 180, Japan, 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 to controller devices utilized to control such variables in industrial processing systems as the temperature, pressure, flow quantity of fluids and the like, and more particularly to a novel controller capable of controlling automatically or non-automatically.

According to the invention, there is provided a controller comprising an input impedance circuit having an input terminal and an output terminal, means to impress upon said input terminal a signal related to a measured signal from a processing system, an operational amplifier to produce an output signal controlling a supply to a load, a transfer switch connected between the output terminal of said input impedance circuit and the input terminal of said operational amplifier, a feedback circuit including a capacitor connected between the input terminal of said operational amplifier and its output circuit to store a voltage related to that supplied to the load; and a manual setter including means to modify the voltage stored in said capacitor by external signals such as a manual signal or a signal from a digital computer, the arrangement being such that at the time of the automatic control operation said transfer switch is operated to connect said output terminal of said input impedance circuit to the input terminal of the operational amplifier, whereas at the time of the control operation by said external signal said transfer switch is operated to disconnect said output terminal of said input impedance circuit from said input terminal of the operational amplifier, thus modifying the voltage stored in the capacitor in the feedback circuit by the signal supplied by said setter, a source of supply to energise said operational amplifier and means to

modify the output signal of said operational amplifier. The means to modify the output may be a limiter circuit connected to the output terminal of said operational amplifier, and wherein the upper and lower limit set values of said limiter circuit are variable, said limiter circuit comprising a variable resistor having two sliding brushes, a first transistor rendered ON and OFF in accordance with the relative magnitude between the voltage produced at one brush of said variable resistor and the voltage impressed upon the input terminal of said limiter circuit, a second transistor rendered ON and OFF by said first transistor, and a third transistor rendered ON and OFF in accordance with the relative magnitude between the voltage produced at the other brush and at the input terminal of said limiter circuit.

According to another aspect of the invention, the limiter circuit comprises a variable resistor having two brushes, a first comparator supplied with a voltage produced at one of said brushes and voltage related to the output voltage supplied to said load, a first diode rendered ON and OFF by the output from said comparator, a second comparator supplied with the voltage produced at the other of said brushes and a voltage related to said output voltage supplied to said load, a second diode rendered ON and OFF in accordance with the output from said second comparator. Objects and advantages of this invention will become apparent from the following detailed description of examples of the invention taken in conjunction with the accompanying drawings, in which:

Figure 1 shows a circuit diagram of a controlling device;

Figure 2A shows a limiter characteristic of an upper and lower limiter circuit;

Figure 2B shows the configuration of a limiter circuit having the configuration of Figure 2A;

Figure 3A shows an input-output characteristic of the controlling device shown in Figure 1 when controlled manually by means of an upper and lower limiter circuit;

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Figure 3B shows a perspective view of an upper and lower limiter circuit that exhibits the characteristic shown in Figure 3A;

Figure 4 and 5 are circuit diagrams similar to Figure 1 but with modified upper-lower limiter circuits; and

Figure 6 shows a further circuit diagram.

Description of the Preferred Embodiments

In the following description and claims the term "Manual Control" is used to mean not only a manual control with the hands of man but also an adjustment effected by an external signal from a digital computer and the like.

The embodiment of this invention shown in Fig. 1 comprises input terminals T_1 and T_2 to receive a signal ϵ related to the difference between a measured signal from a processing system and a set value or reference signal, an operational amplifier OA_1 , a capacitor C_M and a resistor R_I . Capacitor C_M and resistor R_I are connected in parallel to constitute an input impedance circuit $I.I$ for the operational amplifier OA_1 , whereas a feedback circuit thereof is comprised by a holding capacitor C_M . A transfer switch for switching the operation between a control by an external signal and an automatic control is connected between input impedance circuit $I.I$ and operational amplifier OA_1 . A manual setter MC is provided comprising manual switches S_1 and S_D and sources E_1 and E_2 for manual controls. A load Lo is connected across output terminals T_3 and T_4 .

To provide the automatic control, transfer switch S_1 is thrown to a contact S_A whereby signal ϵ related to the deviation signal is applied to the input terminal of the operational amplifier OA_1 via input impedance circuit $I.I$. The operational amplifier operates to amplify this input signal to supply an output signal to load Lo . The output voltage E_o appearing across load Lo is fed back to the input side of the operational amplifier OA_1 via capacitor C_M so that operational amplifier OA_1 operates to reduce its input to zero. As a result, capacitor C_M stores a voltage corresponding to output voltage E_o across load Lo . When the gain of the operational amplifier OA_1 is made sufficiently large there is a relation expressed by equation (1) between deviation signal ϵ and the load voltage E_o .

$$E_o = \epsilon \cdot \frac{CI}{CM} \left(1 + \frac{1}{RI \cdot CI \cdot S} \right) \\ = \epsilon \cdot Kp \cdot \left(1 + \frac{1}{TI \cdot S} \right) \quad (1)$$

where

$$S : \frac{d}{dt} \\ Kp : \frac{CI}{CM} \\ TI : RI \cdot CI$$

As can be noted from equation (1), the device shown in Fig. 1 functions as a control which provides proportionality and integrating operations whose proportionality gain Kp is determined by CI/CM and integrating time T_I by $R_I \cdot C_I$.

To provide the manual control, transfer switch S_1 is thrown to contact S_H . Then one terminal of input impedance circuit $I.I$ is disconnected from the input terminal of operational amplifier OA_1 and connected to a point of common potential (shown as the ground) via transfer switch S_1 . The circuit comprising operational amplifier OA_1 and capacitor C_M operates as a holding amplifier to provide an output determined by the voltage stored in capacitor C_M . For this reason transfer from the automatic control to the manual control does not vary the output voltage E_o . Thus, it is possible to provide bumpless switching from the automatic control to the manual control without the necessity of performing a balancing operation. After switching to the manual control condition in this manner, either one of manual control switches S_1 or S_D is operated to apply to operational amplifier OA_1 a positive or negative voltage from positive source E_1 or negative source E_2 via a resistor r to vary the charging voltage of capacitor C_M thus performing the manual control. More particularly, when manual control switch S_1 is closed, the output voltage E_o will increase with a time constant determined by the value of resistor r and the capacitance of capacitor C_M . Whereas when manual control switch S_D is closed the same time constant as above described. When neither of manual control switches S_1 or S_D is closed, the charge of capacitor C_M will be held so that the output voltage E_o is maintained at a definite value. Under these manual control conditions, since one terminal of the input impedance circuit $I.I$ is grounded through manual-automatic transfer switch S_1 , this grounded terminal will always be maintained at the zero potential irrespective of the value of the signal ϵ related to the deviation signal. For this reason, transfer of the transfer switch S_1 from contact S_H to contact S_A to switch the condition from manual to automatic control does not cause rapid change in the output voltage E_o . Thus, it is possible to provide bumpless switching between the manual control condition and the automatic control condition without the necessity of performing a balancing operation regardless of the value of signal ϵ related to the deviation signal.

In this manner, the control enables bumpless switching between automatic control and manual control effected by an external signal without performing a balancing operation.

An output transistor TrO amplifies further

the output signal from operational amplifier OA_1 to apply an output voltage E_o across output terminal T_3 and T_4 . A signal, consisting of a train of positive or negative pulses, for example, may be delivered by a digital controller, not shown, and this pulse train signal may be applied to the input terminal of the operational amplifier OA_1 through resistor r , under control of a switch.

In this modification, however, to provide a back-up operation of the digital controller, the manual-automatic transfer switch S_1 is thrown to contact S_H and the switch controlling the pulse train is closed. These switches may be comprised by transistor switching elements or relays operated synchronously with a signal from the digital controller. Thus the pulse train signal from the digital controller is impressed upon the input terminal of operational amplifier OA_1 through resistor r . More particularly, as a result of application of the positive or negative pulse train signal upon the input terminal of operational amplifier OA_1 , the circuit comprising this amplifier and capacitor C_M acts as a holding circuit of the integrating type to provide an analogue output voltage E_o corresponding to the pulse train signal from the digital controller across output terminals T_3 and T_4 .

At the time of the back-up operation of the digital controller, since one terminal of input impedance circuit $I.I$ is grounded in the same manner as the manual control operation, this grounded terminal is always maintained at zero potential irrespective of the value of signal s impressed upon input terminals T_1 and T_2 . For this reason, even when the operation is switched from digital to automatic control by transferring transfer switch S_1 from contact S_M to contact S_A , the output voltage will not be varied rapidly, thus assuring bumpless switching.

A pair of diodes D_1 and D_2 connected in parallel opposition are connected across the input terminal of the operational amplifier OA_1 and the ground. Provision of the diode circuit across the input terminal of the operational amplifier OA_1 and the ground can assure normal operation of the operational amplifier even when the output thereof becomes saturated, because, when the amplifier has become saturated, the diodes D_1 and D_2 prevent the capacitor C_M from being charged, on the application of a signal between T_1 and T_2 , to such an extent as to prevent the amplifier OA_1 from beginning to ramp immediately the signal is removed. The manual setter MC can be driven by an external signal from a digital computer or the like when switches S_1 and S_D of the manual setter MC are comprised by field effect transistor elements and by applying to these elements an upscale pulse or a down scale pulse from a digital computer, for example.

The output from operational amplifier OA_1

is applied to the base electrode of the output transistor T_{ro} via a diode D_3 to obtain an output voltage E_o across a resistor R_o connected between the emitter electrode of the output transistor T_{ro} and the ground. An indicating meter ME is connected to the collector electrode to indicate the output voltage supplied to load L_o .

Between operational amplifier OA_1 and output transistor T_{ro} is connected a limiter circuit LC for upper and lower limits comprising a pair of transistors Tr_L and Tr_H and a variable resistor R_V provided with two sliding brushes B_H and B_L . The limiter circuit being constructed such that transistor Tr_L becomes ON when the output voltage of operational amplifier OA_1 becomes smaller than a lower limit voltage e_L established by brush B_L whereas transistor Tr_H becomes ON when the output voltage of the operational amplifier OA_1 becomes larger than the upper limit voltage e_H established by brush B_H . As a result the operating characteristics of limiter circuit LC is shown by the graph of Fig. 2A, which shows that the output voltage E_o varies linearly in the range between the lower set voltage e_L and the upper set voltage e_H of the output voltage e_o from the operational amplifier OA_1 . The limiter circuit LC has an appearance as shown in Fig. 2B. Thus, set arms or reference markings S_H and S_L for upper and lower limits and respectively connected to brushes B_H and B_L are pivotally mounted on a shaft to cooperate with the dial of indicating meter ME . Upper and lower limit voltages V_H and V_L can be varied by adjusting the position of these arms S_H and S_L .

Provision of such a limiter circuit LC enables the output voltage E_o to be maintained always in a constant range even when the output voltage e_o of operational amplifier OA_1 deviates from said range. The voltage stored in capacitor C_M , when held to provide the output under the manual control condition tends to decrease gradually due to leakage. However, with the limiter circuit LC the output voltage E_o will never become lesser than the lower limit value e_L , thus enabling manual control over a long period of time.

Further, by selecting substantially the same values for the upper and lower limit set voltage e_H and e_L and by making both of them variable, the output voltage E_o can be varied accordingly. More particularly, when the upper and lower limit set voltage e_H and e_L are selected to be substantially the same, the operating characteristics of the limiter circuit LC will become those shown in Fig. 3A so that by simultaneously varying the upper and lower limit set voltage e_H and e_L in the direction of arrow a or b , the output voltage E_o is also varied in the direction of arrow c or d . Accordingly, as shown in Fig. 3B by aligning set markings S_H and S_L for upper and lower

limits and by adjusting them together while observing the indication of the indicating meter ME, manual control can also be made. Under such manual control condition wherein the upper and lower limit voltage e_H and e_L are varied in unison, since capacitor C_M stores the voltage corresponding to the output voltage E_o applies to load L_o it is possible to transfer the operation from the manual control to the automatic control without bumps.

Figs. 4 and 5 show connection diagrams of still further embodiments of this invention utilizing different limiter circuits LC from that shown in Fig. 8.

The limiter circuit LC shown in Fig. 4 comprises three transistors Tr_1 , Tr_2 and Tr_3 , and a variable resistor R_v including two brushes B_H and B_L . In this embodiment, when output voltage e_o from operation amplifier OA_1 becomes lesser than the lower limit set voltage e_L established by brush B_L , transistor Tr_1 is rendered OFF to increase the base potential of transistor Tr_2 , thus rendering conductive transistor Tr_2 . On the other hand, when output voltage e_o of operational amplifier OA_1 increases beyond the upper limit set voltage e_H established by brush B_H , transistor Tr_3 is rendered conductive. In this manner, the output voltage E_o is maintained in a definite range defined by upper and lower limit set voltage e_H and e_L .

The limiter circuit LC shown in Figure 5 comprises a variable resistor R_v having two brushes B_H and B_L , a first comparator Co_H for comparing the output voltage E_o with voltage e_H established by brush B_H and a second comparator Co_L for comparing output voltage E_o with voltage e_L established by brush B_L and diodes D_H and D_L which are controlled as to their ON and OFF states by the outputs from comparators Co_H and Co_L . When output voltage e_o from operational amplifier OA_1 becomes lesser than the lower limit set voltage e_L , comparator Co_L causes diode D_L to become ON. On the other hand, when output voltage e_o from operational amplifier OA_1 becomes larger than the upper limit set voltage e_H causes diode D_H to become ON. In this manner, output voltage E_o is maintained in a safe range defined by upper and lower limit set voltages e_H and e_L .

Figure 6 shows a connection diagram of another embodiment of the novel control including the source circuit. Where an operational amplifier is comprised by a linear integrated circuit and the like, although it is usual to provide positive and negative sources of supply to operate the amplifier, this embodiment utilizes a single DC source. In this embodiment, a power source Ps supplying DC 24 volts is connected to serially connected resistor R_p and Zenor diode D_z to produce a bias voltage $E_B=10$ volts at the juncture between resistor R_p and Zenor diode D_z . Thus,

the resistor R_p and Zenor diode D_z shift the voltage level of the input signal of operational amplifier OA_1 by a definite voltage. Source terminals of operational amplifiers OA_1 , OA_2 and OA_3 are respectively connected to a zero volt line I_0 and 24 volt line I_{24} connected to power source PS . A measured signal e_M from a processing system, not shown, is supplied across one input terminal T_{11} of operation amplifier OA_1 and a common signal line I_{30} while a reference or set value signal E_S is supplied across the other input terminal T_{12} of operational amplifier OA_1 and common signal line I_{30} . Thus, operational amplifier OA_1 functions to amplify the difference between measured signal e_M from the processing system and reference signal E_S to produce at its output a deviation signal s biased by bias voltage E_B and expressed by an equation

$$s = E_B + \frac{R_f}{R_i} (e_M - E_S)$$

Since the input voltage to the operational amplifier is expressed by

$$\frac{e_M R_f' + E_B R_i'}{R_i' + R_f'}$$

by the suitable selection of values of bias voltage E_B and resistors R_i' and R_f' , operation of the operational amplifier OA_1 in the most suitable operational range can be assured. The deviation signal s is subjected to a proportionating and differentiating operations by means of a circuit including resistor R_D and capacitor C_D and thence imparted with a proportionality gain by means of a circuit including resistors R_{21} and R_{22} . Since these operations are performed by taking the bias line I_B at the reference potential E_B as the reference these operations are performed only for the term

$$R_f$$

$$R_i$$

$(e_M - E_S)$ of the deviation signal s and not for the bias voltage E_B . Output signal from operational amplifier is subjected to proportionating and integrating operations by means of an input impedance circuit; comprising capacitor C_{11} , resistor R_{11} and resistors R_{12} and R_{13} and of a circuit including capacitor C_{21} and operational amplifier OA_2 to obtain output voltage E_{o1} . Since this output voltage E_{o1} utilizes the voltage of bias line I_B at the reference voltage the output signal is shifted by the circuit comprising transistor Tr_{01} and Tr_{02} to provide a current output signal I_o and a voltage output signal E_o at output ter-

minals T_3 and T_4 , said output signals I_o and E_o utilizing the voltages of zero volt line I_o and common signal line I_{sc} as the references. The transistor TR_{o1} (equivalent to TR_o in

Figure 1) shifts the voltage level of the output signal of operational amplifier OA_1 by a definite voltage. The output voltage E_{o1} of this controller is expressed by equation (2).

$$E_{o1} = \frac{R_f}{R_i} \cdot \frac{1}{n} \cdot \alpha \cdot \frac{1+n \cdot RD \cdot CD \cdot S}{1+RD \cdot CD \cdot S} \cdot \frac{CI}{GM} \cdot \left(1 + \frac{1}{m \cdot CI \cdot RI \cdot S}\right) (e_x - E_s) \quad (2)$$

10 where

$$\frac{1}{n} = \frac{R_{32}}{R_{31} + R_{32}}$$

$$\frac{1}{\alpha} = \frac{R_{21}}{R_{21} + R_{22}}$$

and

$$\frac{1}{m} = \frac{R_{12}}{R_{11} + R_{12}}$$

15 In this embodiment, however, since the zero volt line of the source and the zero volt line of the signal are comprised by a signal common line there is a fear that the voltage drop caused by the source current might cause an error of the signal. To avoid this it is advantageous to separate zero volt line I_o and common line I_{sc} and connect them to the source at a point in the system.

20 While the invention has been shown and described in terms of certain preferred embodiments thereof it is to be understood that the invention is not limited to these particular embodiments and that many changes and modifications will occur to one skilled in the art without departing from the true scope of the invention as defined in the appended claims.

WHAT WE CLAIM IS:—

35 1. An industrial process controller comprising an input impedance circuit having an input terminal and an output terminal, means to impress upon said input terminal a signal related to a measured signal from a processing system, an operational amplifier to produce an output signal controlling a supply to a load, a transfer switch connected between the output terminal of said input impedance circuit and the input terminal of said operational amplifier, a feedback circuit including a capacitor connected between the input terminal of said operational amplifier and its output circuit to store a voltage related to that supplied to the load; a manual setter including means to modify the voltage stored in said capacitor by external signals such as a manual signal or a signal from a digital

computer, the arrangement being such that at the time of the automatic control operation said transfer switch is operated to connect said output terminal of said input impedance circuit to said input terminal of said operational amplifier whereas at the time of the control operation by said external signal said transfer switch is operated to disconnect said output terminal of said input impedance circuit from said input terminal of said operational amplifier, thus modifying the voltage stored in said capacitor in said feedback circuit by the signal supplied by said setter, a source of supply to energize said operational amplifier and means to modify the output signal of said operational amplifier.

2. An industrial process controller according to Claim 1, in which said means to modify the output signal of said operational amplifier consist of means to shift the voltage level of the output signal of said operational amplifier by a definite voltage, means being provided also to shift the voltage level of the input signal of said operational amplifier by the same amount.

3. An industrial process controller according to Claim 1, in which a limiter circuit is connected to the output circuit of said operational amplifier, and wherein the upper and lower set values of said limiter circuit are variable, said limiter circuit comprising a variable resistor having two sliding brushes, a first transistor connected so that it becomes ON when the output voltage of said operational amplifier becomes smaller than a lower limit voltage established by one of said brushes, and a second transistor connected so that it becomes ON when the output voltage of said operational amplifier becomes larger than the upper limit voltage established by the second of said brushes, the arrangement being such that the output voltage of said controller varies linearly between the lower set voltage and the upper set voltage of the output voltage of said operational amplifier.

4. An industrial process controller according to Claim 1, in which a limiter circuit is connected to the output terminal of said operational amplifier, and wherein the upper and lower limit set values of said limiter circuit are variable, said limiter circuit comprising a variable resistor having two sliding brushes, a first transistor rendered ON and OFF in accordance with the relative magnitude be-

minals T_3 and T_4 , said output signals I_o and E_o utilizing the voltages of zero volt line I_o and common signal line I_{so} as the references. The transistor TR_{o1} (equivalent to TR_o in

$$E_{o1} = \frac{R_f}{R_i} \cdot \frac{1}{n} \cdot \frac{1+n \cdot RD \cdot CD \cdot S}{1+RD \cdot CD \cdot S}$$

10 where

$$\frac{1}{n} = \frac{R_{32}}{R_{31} + R_{32}}$$

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and

$$\frac{1}{m} = \frac{R_{12}}{R_{11} + R_{12}}$$

15 In this embodiment, however, since the zero volt line of the source and the zero volt line of the signal are comprised by a signal common line there is a fear that the voltage drop caused by the source current might cause an error of the signal. To avoid this it is advantageous to separate zero volt line I_o and common line I_{so} and connect them to the source at a point in the system.

20 While the invention has been shown and described in terms of certain preferred embodiments thereof it is to be understood that the invention is not limited to these particular embodiments and that many changes and modifications will occur to one skilled in the art without departing from the true scope of the invention as defined in the appended claims.

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Figure 1) shifts the voltage level of the output signal of operational amplifier OA_1 by a definite voltage. The output voltage E_{o1} of this controller is expressed by equation (2).

$$\frac{CI}{CM} \cdot \frac{1}{m \cdot CI \cdot RI \cdot S} \cdot (e_x - E_s) \quad (2)$$

computer, the arrangement being such that at the time of the automatic control operation said transfer switch is operated to connect said output terminal of said input impedance circuit to said input terminal of said operational amplifier whereas at the time of the control operation by said external signal said transfer switch is operated to disconnect said output terminal of said input impedance circuit from said input terminal of said operational amplifier, thus modifying the voltage stored in said capacitor in said feedback circuit by the signal supplied by said setter, a source of supply to energize said operational amplifier and means to modify the output signal of said operational amplifier.

2. An industrial process controller according to Claim 1, in which said means to modify the output signal of said operational amplifier consist of means to shift the voltage level of the output signal of said operational amplifier by a definite voltage, means being provided also to shift the voltage level of the input signal of said operational amplifier by the same amount.

3. An industrial process controller according to Claim 1, in which a limiter circuit is connected to the output circuit of said operational amplifier, and wherein the upper and lower set values of said limiter circuit are variable, said limiter circuit comprising a variable resistor having two sliding brushes, a first transistor connected so that it becomes ON when the output voltage of said operational amplifier becomes smaller than a lower limit voltage established by one of said brushes, and a second transistor connected so that it becomes ON when the output voltage of said operational amplifier becomes larger than the upper limit voltage established by the second of said brushes, the arrangement being such that the output voltage of said controller varies linearly between the lower set voltage and the upper set voltage of the output voltage of said operational amplifier.

4. An industrial process controller according to Claim 1, in which a limiter circuit is connected to the output terminal of said operational amplifier, and wherein the upper and lower limit set values of said limiter circuit are variable, said limiter circuit comprising a variable resistor having two sliding brushes, a first transistor rendered ON and OFF in accordance with the relative magnitude be-



tween the voltage produced at one brush of said variable resistor and the voltage impressed upon the input terminal of said limiter circuit, a second transistor rendered
5 ON and OFF by said first transistor, and a third transistor rendered ON and OFF in accordance with the relative magnitude between the voltage produced at the other brush and at the input terminal of said limiter
10 circuit.

5. An industrial process controller according to Claim 1, in which a limiter circuit is connected to the output terminal of said operational amplifier, and wherein the upper and
15 lower limit set values of said limiter circuit are variable, said limiter circuit comprising a variable resistor having two brushes, a first comparator supplied with a voltage produced at one of said brushes and voltage related to
20 the output voltage supplied to said load, a first diode rendered ON and OFF by the output from said comparator, a second comparator supplied with the voltage produced at the other of said brushes and a voltage related
25 to said output voltage supplied to said load, a second diode rendered ON and OFF in

accordance with the output from said second comparator.

6. An industrial process controller according to any one of Claims 3 to 5, provided
30 with an indicating meter connected to indicate on a dial the output voltage of the controller, said two brushes being pivotally mounted on a shaft to co-operate with the
35 dial.

7. An industrial process controller substantially as described with reference to Figures 1, 2A, 2B, 3B of the accompanying drawings.

8. An industrial process controller substantially as described with reference to
40 Figure 4 of the accompanying drawings.

9. An industrial process controller substantially as described with reference to Figure 5 of the accompanying drawings.

10. An industrial process controller sub-
45 stantially as described with reference to Figure 6 of the accompanying drawings.

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