

PATENT SPECIFICATION (11)

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(54) FREQUENCY-TO-VOLTAGE CONVERTER

(71) We, KABUSHIKI KAISHA DAINI SEIKOSHA, a Japanese body corporate of 6-31-1, Kameido, Koto-ku, Tokyo, 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 frequency-to-voltage converters.

One known frequency-to-voltage converter—sometimes known as an integral frequency-to-voltage converter—consists of a monostable multi-vibrator triggered by an oscillating input signal, and an integrating circuit for receiving and smoothing a pulsiform output signal from the multi-vibrator to produce a voltage signal therefrom. This frequency-to-voltage converter cannot be used as a power source, since power consumption affects the converting linearity badly. If a relatively high power source is required, a DC power amplifier of high gain and high power is conventionally provided to amplify the output signal of the frequency-to-voltage converter. The DC power amplifier should be a highly precise linear amplifier for maintaining the converting linearity. However, it is very difficult to design a DC power amplifier having both precise linearity and high power, and many linear DC power amplifiers are not suitable for use in such a power source because their operation suppresses power sufficiency. Therefore, to produce high power using a DC amplifier, a far larger DC amplifier and power source are required compared to the output power taken. The combination of a frequency-to-voltage converter and a DC amplifier is not, therefore, practical for supplying high power.

According to the present invention, there is provided a frequency-to-voltage converter comprising: a switching circuit having an input arranged to be connected to an electrical power source; a smoothing filter connected to an output of the switching circuit; a frequency-to-voltage converting circuit for generating an output signal which has a voltage level related to the frequency of

an oscillating signal applied to an input of the converting circuit; and a feedback circuit connected to receive an output signal from the smoothing circuit, the arrangement being such that the switching circuit is controlled by a pulsiform control signal the width of each pulse of which is a function of the difference between the voltage level of the output signal of the converting circuit and the voltage level of an output signal of the feedback circuit.

In the preferred embodiment the converter includes a differential amplifier having an inverting input connected to receive the output signal from the converting circuit and a non-inverting input connected to receive the output signal of the feedback circuit, the differential amplifier, in operation, producing an output signal, the voltage level of which is a function of the difference between the voltage level of the output signal of the converting circuit and the voltage level of the output signal of the feedback circuit.

The converter preferably comprises a comparison circuit connected to receive an output signal from a triangle wave generator and the output signal from the differential amplifier for producing the said pulsiform control signal therefrom.

Preferably the smoothing filter, feedback circuit, differential amplifier, comparison circuit and switching circuit are connected in a negative feedback loop.

According to a further aspect of the present invention there is provided a driving circuit for a motor, for example a synchronous motor, comprising a variable frequency oscillator for producing an oscillating output signal, an amplifier connected to receive the output signal from the oscillator and to drive the motor, and the frequency-to-voltage converter as re-cited above connected to receive the output signal from the oscillator and to supply an output signal to the amplifier.

Said amplifier may be a power amplifier.

The invention is illustrated, merely by way of example, in the accompanying drawings, in which:—

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Figure 1 is a block diagram of a frequency-to-voltage converter according to the present invention;

Figure 2 is a waveform Diagram showing the waveform of signals at various parts of the frequency-to-voltage converter of Figure 1; and

Figure 3 is a block diagram of a driving circuit including the frequency-to-voltage converter of Figure 1.

Referring to Figure 1 there is illustrated a frequency-to-voltage converter according to the present invention. A relatively high power unregulated DC power source 1 has an output terminal which is connected to a smoothing filter 3 through a switching circuit 2. The switching circuit 2 may consist of a solid state switching element such as a transistor. A triangular wave signal generator 4 generates an isosceles triangle wave voltage output signal V_1 as shown in Figure 2. An integral frequency-to-voltage converting circuit 5 includes a monostable multi-vibrator and an integrating circuit, the monostable multi-vibrator receiving an oscillating input signal as a trigger signal and the integrating circuit receiving a pulsiform output signal from the mono-stable multi-vibrator and generating therefrom an output signal whose voltage level is related to the frequency of the oscillating input signal. The output signal from the frequency-to-voltage converting circuit 5 is fed to an inverting input of a differential amplifier 6. A feedback circuit 7 receives a voltage output signal from the smoothing signal 3 and feeds it to a non-inverting input of the differential amplifier 6. The differential amplifier 6 generates, at its output, an output voltage $V_2 = V_d - V_o$, where the voltage V_d is the voltage of the output signal of the smoothing filter 3 and the voltage V_o is the voltage of the output signal of the frequency-to-voltage converting circuit 5.

A comparison circuit 8 compares the voltage of the voltage signal V_1 and the output voltage V_2 from the differential amplifier 6, and generates a pulsiform signal, each pulse of which has a pulse width T_w corresponding to the duration when a voltage difference ($V_1 - V_2$) is positive. This pulsiform signal controls the switching circuit 2, and increases the voltage of the output signal of the feedback circuit 7 by increasing the pulse width T_w when the voltage V_2 is decreasing and by decreasing the pulse width T_w when the voltage V_2 is increasing. When V_2 is increasing the switching circuit 2 effects a decrease in the voltage of the output signal of the feedback circuit 7. When the voltage V_2 is decreasing the switching circuit 2 effects an increase in the voltage of the output signal of the feedback circuit 7. Thus, a negative feedback loop is

formed and includes the smoothing filter 3, the feedback circuit 7, the differential amplifier 6, the comparison circuit 8 and the switching circuit 2 for making the voltage of the output signal of the feedback signal 7 follow that of the frequency-to-voltage converting circuit. Thus the voltage of the output signal of the smoothing filter 3 always and exactly linearly follows that of the frequency-to-voltage converting circuit.

Thus, a relatively high power frequency-to-voltage converter is obtained in which the DC voltage of the output signal from the smoothing filter 3 is controlled so that the DC voltage level is proportional to the frequency of the oscillating input signal applied to the frequency-to-voltage converting circuit 5. The output of the frequency-to-voltage converting circuit 5 is controlled by a switching operation and does not rely upon linear properties of circuits or elements, e.g. a linear DC amplifier. The power losses in the frequency-to-voltage converter are relatively small in spite of its relatively high power output and, furthermore, very precise and accurate conversion of frequency-to-voltage is obtained due to the provision of the negative feedback loop.

Figure 3 is a block diagram illustrating a driving circuit of a synchronous motor M and including a frequency-to-voltage converter 9 as illustrated in Figure 1. The frequency-to-voltage converter 9 receives an oscillating output signal from a variable frequency oscillator 10 whose frequency is related to the driving speed of the synchronous motor M. The output signal from the frequency-to-voltage converter 9 is fed to a power amplifier 11, which also receives the output signal from the oscillator 10, and serves as a power source to the synchronous motor M.

The driving circuit operates as follows. The output signal from the oscillator 10 is amplified by the amplifier 11 which produces an output power signal. The output power signal drives the synchronous motor M at a driving speed related to the frequency of the output signal of the oscillator 10. The power source for driving the synchronous motor M is derived from the output signal of the frequency-to-voltage converter 9, the voltage of the output signal of the power amplifier 11, i.e. the driving voltage of the synchronous motor M, changes in response to the frequency of the output signal from the oscillator 10. A lower frequency output signal from the oscillator 10 results in a lower driving speed of the synchronous motor M and this is accompanied by a lower driving voltage and vice-versa. Therefore, excessive current consumption, which would otherwise be caused by an impedance decrease in the windings of the synchronous motor M on account of the

lower driving speed is prevented by lowering the driving voltage. On the other hand, insufficient current supplied to the synchronous motor M caused by impedance increase in the windings on account of a higher driving speed of the synchronous motor is prevented by increasing the driving voltage.

Synchronous motors may be damaged, for example, if they are subjected to excessive temperature rise which may result in burning out of the windings, if excessive electric current is applied during either very low and continuous driving speeds, or very frequent intermittent driving, whilst very high driving speeds decrease the electrical current so that the desired torque cannot be maintained. These problems are solved with the driving circuit of Figure 3.

Further, this driving circuit is relatively simple in construction and reduces heat generation because the driving voltage is controlled without any power loss in the power amplifier 11 because of the voltage control exercised by the frequency-to-voltage converter 9. Thus the driving circuit is subject to less power loss and to less temperature rise.

WHAT WE CLAIM IS:—

1. A frequency-to-voltage converter comprising: a switching circuit having an input arranged to be connected to an electrical power source; a smoothing filter connected to an output of the switching circuit; a frequency-to-voltage converting circuit for generating an output signal which has a voltage level related to the frequency of an oscillating signal applied to an input thereof; and a feedback circuit connected to receive an output signal from the smoothing circuit, the arrangement being such that the switching circuit is controlled by a pulsiform control signal the width of each pulse of which is a function of the difference between the voltage level of the output signal of the converting circuit and the voltage level of an output signal of the feedback circuit.

2. A converter as claimed in claim 1 including a differential amplifier having an inverting input connected to receive the out-

put signal from the converting circuit and a non-inverting input connected to receive the output signal of the feedback circuit, the differential amplifier, in operation, producing an output signal, the voltage level of which is a function of the difference between the voltage level of the output signal of the converting circuit and the voltage level of the output signal of the feedback circuit.

3. A converter as claimed in claim 2 comprising a comparison circuit connected to receive an output signal from a triangle wave generator and the output signal from the differential amplifier for producing the said pulsiform control signal therefrom.

4. A converter as claimed in claim 3 in which the smoothing filter, feedback circuit, differential amplifier, comparison circuit and switching circuit are connected in a negative feedback loop.

5. A frequency-to-voltage converter substantially as herein described with reference to and as shown in Figure 1 of the accompanying drawings.

6. A driving circuit for a motor, comprising a variable frequency oscillator for producing an oscillating output signal, an amplifier connected to receive the output signal from the oscillator and to drive the motor, and a frequency-to-voltage converter as claimed in any preceding claim and connected to receive the output signal from the oscillator and to supply an output signal to the amplifier.

7. A driving circuit as claimed in claim 6 in which said amplifier is a power amplifier.

8. A driving circuit as claimed in claim 6 or 7 in which the motor is a synchronous motor.

9. A driving circuit as claimed in claim 6 and substantially as herein described with reference to and as shown in Figure 3 of the accompanying drawings.

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lower driving speed is prevented by lowering the driving voltage. On the other hand, insufficient current supplied to the synchronous motor M caused by impedance increase in the windings on account of a higher driving speed of the synchronous motor is prevented by increasing the driving voltage.

Synchronous motors may be damaged, for example, if they are subjected to excessive temperature rise which may result in burning out of the windings, if excessive electric current is applied during either very low and continuous driving speeds, or very frequent intermittent driving, whilst very high driving speeds decrease the electrical current so that the desired torque cannot be maintained. These problems are solved with the driving circuit of Figure 3.

Further, this driving circuit is relatively simple in construction and reduces heat generation because the driving voltage is controlled without any power loss in the power amplifier 11 because of the voltage control exercised by the frequency-to-voltage converter 9. Thus the driving circuit is subject to less power loss and to less temperature rise.

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2. A converter as claimed in claim 1 including a differential amplifier having an inverting input connected to receive the out-

put signal from the converting circuit and a non-inverting input connected to receive the output signal of the feedback circuit, the differential amplifier, in operation, producing an output signal, the voltage level of which is a function of the difference between the voltage level of the output signal of the converting circuit and the voltage level of the output signal of the feedback circuit.

3. A converter as claimed in claim 2 comprising a comparison circuit connected to receive an output signal from a triangle wave generator and the output signal from the differential amplifier for producing the said pulsiform control signal therefrom.

4. A converter as claimed in claim 3 in which the smoothing filter, feedback circuit, differential amplifier, comparison circuit and switching circuit are connected in a negative feedback loop.

5. A frequency-to-voltage converter substantially as herein described with reference to and as shown in Figure 1 of the accompanying drawings.

6. A driving circuit for a motor, comprising a variable frequency oscillator for producing an oscillating output signal, an amplifier connected to receive the output signal from the oscillator and to drive the motor, and a frequency-to-voltage converter as claimed in any preceding claim and connected to receive the output signal from the oscillator and to supply an output signal to the amplifier.

7. A driving circuit as claimed in claim 6 in which said amplifier is a power amplifier.

8. A driving circuit as claimed in claim 6 or 7 in which the motor is a synchronous motor.

9. A driving circuit as claimed in claim 6 and substantially as herein described with reference to and as shown in Figure 3 of the accompanying drawings.

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