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(54) Title: BALLAST

(57) Abstract

A ballast filter scheme in which the ballast can operate at a total harmonic distortion of power line current of less than 10 %. Power dissipated by the filter when at a THD of less than 10 % is relatively low. The input impedance of the ballast is designed to be no greater than twice the equivalent filter impedance of a front end filter and no less than the equivalent filter impedance/1.5. The filter includes a transformer having a core which at times operates within the non-linear region of its B-H curve under nominally rated ballast load conditions.

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Ballast.

This invention relates generally to a ballast having an input for receiving from a utility power line under nominally rated ballast load conditions an alternating current having a peak amplitude and characterized by a ballast input equivalent impedance Z_{IN} as measured across the ballast input and further comprising a filter characterized by an equivalent impedance Z_{eq}, coupled to the ballast input and including a filter output, an inductor having a core and a capacitor coupled to the output of the filter and at least a portion of the inductor, the core being substantially characterized by a B-H curve having a substantially linear region and a substantially non-linear region with a substantially uniform flux density existing throughout the core when in the non-linear region of its B-H curve wherein under nominally rated ballast load conditions the core operates within the non-linear region of its B-H curve when at least at the peak amplitude of the alternating current.

The invention also relates to a method of operating a ballast having a ballast input, a ballast input impedance Z_{IN} as measured the across the ballast input and a filter coupled to the ballast input, having a filter output and characterized by an equivalent impedance Z_{eg}, comprising the steps of:

receiving at the ballast input from a utility power line under nominally rated ballast load conditions an alternating current having a peak amplitude;

drawing the alternating current through the filter, the filter further including an inductor having a core and a capacitor, the capacitor being coupled to at least a portion of the inductor and one of the filter output and ballast input, the core being substantially characterized by one B-H curve having a substantially linear region and a substantially non-linear region with a substantially uniform flux density existing throughout the core when in the non-linear region;

maintaining the core within the non-linear region of its B-H core when at least at the peak amplitude of the alternating current under nominally rated ballast load conditions.

Such a ballast and such a method are known from US 4,672,522. In general the filter in a ballast functions to reduce the amount of total harmonic distortion. Total harmonic distortion (THD) is a term which reflects and can be calculated to determine the amount of harmonic distortion present in current supplied to a ballast from a utility power line. Electronic ballasts are well known for drawing line current rich in harmonic content. Filters are provided at the front end of an electronic ballast to limit the harmonics drawn from the utility power line.

Many conventional electronic ballasts operate at a THD ranging from about 14% to 18% through the use of an LC low pass filter. Demands recently imposed by the utility industry as well as by the general public typically require the line current THD drawn by the ballast to be less than 10%.

In meeting this lower THD level, a conventional LC filter must increase its low pass attenuating characteristics at the sacrifice of efficiency, that is, by consuming far more power.

It is an object of the invention to provide an improved ballast with which the THD can be reduced while maintaining a relatively high ballast efficiency, that is, without a substantial increase in power dissipation of the ballast filter.

A ballast as described in the opening paragraph is therefore according to the invention characterized in that the relationship between the equivalent impedance Z_{eq} and ballast input impedance Z_{IN} under nominally rated ballast load conditions varies as follows: $0.5 \leq Z_{eq}/Z_{IN} \leq 1.5$.

A method as described in the second paragraph is therefore according to the invention characterized by varying the relationship between the equivalent impedance Z_{eq} and the ballast input impedance Z_{IN} under nominally rated ballast load conditions such that $0.5 \leq Z_{eq}/Z_{IN} \leq 1.5$.

The filter through the varying relation between equivalent impedance Z_{eq} and ballast input impedance Z_{IN} in combination with the inductor core operating within the non-linear region of its B-H curve when at least at the peak amplitude of the alternating current provides sufficient harmonic attenuation to ensure an acceptable THD level of less than 10% while maintaining a relatively high ballast efficiency. In particular, by limiting the ballast input impedance Z_{IN} to being no greater than twice the equivalent impedance Z_{eq}, the level of THD is maintained at an acceptable level. As ballast input impedance Z_{IN} begins to approach equivalent impedance Z_{eq}, the THD is continually lowered. Ballast efficiency is maintained at a relatively high level by operating the core within the non-linear region of its B-H curve at levels approaching as well as at the peak amplitude of the alternating current drawn by the ballast.

Preferably the capacitor is coupled between the ballast input and the filter output. Alternatively, the capacitor can be coupled between a tap of the inductor and one of the filter output and ballast input.

In a preferred embodiment of a ballast according to the invention an additional inductor and a resistor are serially connected to the capacitor to further lower the level of THD.

Preferably the method according to the invention further includes the step of filtering harmonics by passing a portion of the harmonics through the capacitor.

In the drawing FIG. 1 is a partial block diagram and partial electrical schematic of a ballast in accordance with the invention;

FIG. 2 is an electrical schematic of the filter of FIG. 1 illustrating the measurements to be taken in determining its equivalent impedance;

FIG. 3 is a B-H curve of a transformer core within the filter of FIG. 1 traversed under nominal excitation;

FIG. 4 is a plot of ballast filter inductance versus current flow through the inductance with the filter output short circuited;

FIG. 5 is a plot of THD versus the normalized equivalent filter impedance under nominal excitation; and

FIG. 6 is a plot of the power dissipated by the filter inductance versus the normalized equivalent filter impedance under nominal excitation.

Referring now to FIG. 1, a ballast 10 includes a filter 20, a rectifier 30 and an inverter 40. A utility power line nominally at voltage V_L and supplying line current I_L to ballast 10 is represented by an AC source 11. Source 11 is connected to a pair of input terminals 12 and 13 of ballast 10. Filter 20 serves, in part, to remove any electromagnetic interference (EMI) from reaching the utility power line from ballast 10. The filtered AC signal is supplied to rectifier 30 through a pair of filter output terminals 14 and 15. Rectifier 30, which typically is either of the half-bridge or full-bridge type, produces a varying DC signal to inverter 40. Although not shown in FIG. 1, the voltage produced by rectifier 30 can be boosted through any well known technique such as, but not limited to, a voltage doubler, up-converter or the like in providing a suitable, relatively steady state DC voltage to the input of inverter 40. Inverter 40 can be, but is not limited to, a current fed, half-bridge type and provides an alternating signal across a pair of output terminals 18 and 19 of ballast 10 for powering a lamp load 50.

Filter 20 includes a transformer T having a magnetic core and a pair of inductors L1 and L2. Inductors L1 and L2 are commonly referred to as a split choke or coupled inductor. Inductor L1 is connected between ballast input terminal 12 and filter output terminal 14. Also connected between ballast input terminal 12 and filter output terminal 14 is the serial combination of a capacitor C1, an inductor L3 and a resistor R. The serial combination need not be connected to ballast input terminal 12. For example, connection also can be made to a tap of inductor L1 depending, in part, on the attenuation required. Capacitor C1 should therefore be considered as being coupled to at least a portion of inductor L1 and filter output terminal 14. Inductors L1 and L2 also can be designed as a single inductor with the serial combination of capacitor C1, inductor L3 and resistor R connected at one end to a tap of this single inductor and at the other end to filter output terminal 14.

Connected between ballast input terminal 13 and filter output terminal 15 is inductor L2. One end of capacitor C2 is, connected to the junction joining together inductor L1, resistor R and filter output terminal 14. The other end of capacitor C2 is connected to the junction joining together inductor L2 and filter output terminal 15.

Inductor L3 serves along with capacitor C1 to attenuate, in part, the EMI exiting ballast 10 into AC source 11. Resistor R serves to lower the Q of the resonant circuit formed by inductor L3 and capacitor C2.

The combination of capacitor C2 and inductors L1 and L2 is tuned to just about the third harmonic of power line current I_L. Inductor L1 and capacitor C1 serve to attenuate higher harmonics. Capacitor C2 also slows down the transition period in the rectangular waveform generated by rectifier 30. Other harmonics generated by rectifier 30 as seen by filter 20 are also filtered by inductor L1.

Typical nominal filter component values for a lamp load of two 40 watt, 120 volt series connected fluorescent lamps include resistor R at 33 ohms, 1/2 watt; capacitor C1 at 1.3 microfarad; capacitor C2 at 2.8 microfarad; inductor L3 at 820 microhenries and transformer T at 69 watts, 120 volts, 60 Hz.

Referring now to FIG. 2, filter 20 can be defined by an equivalent impedance $Z_{eq} = V_{oc}/I_{sc}$. Voltage V_{oc} is the open circuit voltage across filter output terminals 14 and 15. Current I_{sc} is the short circuit current flowing between output terminals 14 and 15. An AC source 11' is one fourth the nominal line voltage V_L of AC source 11.

As shown in FIG. 3, the core associated with the split choke/coupled inductor of filter 20, that is, the core associated with inductors L1 and L2 is substantially characterized by a B-H curve having a substantially linear region "a" and substantially non-linear regions "b". As shown in FIG. 4, the inductance of inductors L1 and L2 is designed to operate within non-linear regions b at and near the peak amplitude of the alternating line current I_L. In particular, the core operates within its non-linear region when at the peak amplitude of the alternating line current I_L under nominally rated ballast load conditions. Power losses consumed by the core under nominally rated ballast load conditions are therefore minimized.

The plot of inductance in millihenries versus RMS line current in milliamps, shown in FIG. 4, is based on a 59 watt ballast inductance (i.e. combination of inductors L1 and L2) at 120 Volts under unloaded conditions, that is, without connection of lamp load 50 to ballast 10. Operation within the non-linear region of this B-H curve begins when current flowing through the inductance increases beyond about 100 milliamps.

In contrast thereto, a conventional ballast filter having a split choke/coupled inductor operates substantially within the linear region rather than the non-linear region of the associated core's B-H curve when under nominally rated ballast load conditions. Undesirable power losses within the conventional filter result.

Referring now to FIG. 5, a plot of the THD within power line current I_L versus the normalized equivalent impedance of filter 20 is shown. As used herein, THD = $\sqrt{\Sigma I_n^2/I_1^2}$, wherein I_1 is that component of current I_L at the fundamental frequency, n = an integer greater than 1 and I_n is a harmonic of current I_L. In other words, I_L = $\sqrt{I_1^2 + I_2^2 + \ldots}$. The normalized equivalent impedance of filter 20 is defined as the ratio of Z_{eq}/Z_{IN}.

The relationship of THD to the normalized equivalent impedance of filter 20 shown in FIG. 5 is based on a nominally rated 69 watt ballast having transformer T with a core volume of approximately 27.3 cm^3. In order to maintain a THD of approximately 16 percent or less, the normalized equivalent impedance of filter 20 is equal to or greater than

0.5. In limiting losses dissipated by inductors L1 and L2 as current I_L increases, this ratio is preferably no greater than 1.5. As shown in FIG. 6 for a nominally rated 69 watt ballast having a transformer T with a core volume of 27.3 cm^3, power dissipated by inductors L1 and L2 ranges between about 3.2 watts and about 6 watts when the normalized equivalent filter impedance is at 0.5 and 1.5, respectively.

By operating in the non-linear region of the B-H curve of the core associated with inductors L1 and L2, at least when at or near the peak amplitude of current I_L, the relationship between equivalent impedance Z_{eq} and ballast input impedance Z_{IN} varies as follows: $0.5 \leq Z_{eq}/Z_{IN}$ (normalized equivalent filter impedance). Beyond the desirable upper limit of this ratio, that is, at a value greater than 1.5, unacceptably high power losses associated with inductors L1 and L2 results.

The balance struck between THD and power dissipated by filter 20 is achieved by limiting the normalized equivalent impedance of filter 20 to a range between and including 0.5 and 1.5. The level of THD can be further limited by raising the minimum value of the normalized equivalent filter impedance so as to conform to the 10% or less range recently imposed by several power utilities. More particularly, for a 69 watt nominally rated ballast, the normalized equivalent filter impedance can be set to a value of at least 0.65 but no greater than 1.5 such that the THD can be maintained at 10% or less.

The advantageous combination of low THD and relative low inductive power losses at nominally rated ballast load conditions is based, in part, on (1) operating substantially the entire core of transformer T within its non-linear region when near and at the peak amplitude of current I_L and (2) coupling capacitor C1 between at least a portion of inductor L1 and filter output terminal 14.

As can now be readily appreciated, the invention provides an improved method and device for filtering of THD at acceptable levels of power consumption by filter 20. In particular, by maintaining the normalized equivalent impedance of filter 20 (Z_{eq}/Z_{IN}) at no less than 0.5 and no greater than 1.5, an acceptable level of THD can be achieved. When the THD is to be maintained at 10% or less, the normalized equivalent impedance of filter 20 is increased as required above the minimum level of 0.5.

It will thus be seen that the objects set forth above and those made apparent from the preceding description are efficiently attained and since certain changes may be made in the above construction without departing from the spirit and scope of the invention, it is intended that all matter contained in the above description and shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

It is also to be understood that the following claims are intended to cover all the generic and specific features of the invention herein described, and all statements of the scope of the invention which, as a matter of language, might be said to fall therebetween.

CLAIMS

1. A ballast having an input for receiving from a utility power line under nominally rated ballast load conditions an alternating current having a peak amplitude and characterized by a ballast input equivalent impedance Z_{IN} as measured across the ballast input and further comprising a filter characterized by an equivalent impedance Z_{eq}, coupled to the ballast input and including a filter output, an inductor having a core and a capacitor coupled to the output of the filter and at least a portion of the inductor, the core being substantially characterized by a B-H curve having a substantially linear region and a substantially non-linear region with a substantially uniform flux density existing throughout the core when in the non-linear region of its B-H curve wherein under nominally rated ballast load conditions the core operates within the non-linear region of its B-H curve when at least at the peak amplitude of the alternating current, characterized in that the relationship between the equivalent impedance Z_{eq} and input impedance Z_{IN} is as follows: $0.5 \leq Z_{eq}/Z_{IN} \leq 1.5$.

2. The ballast of claim 1, wherein the capacitor is coupled between the input of the ballast and the output of the filter.

3. The ballast of claim 1, further including an additional inductor and a resistor serially connected to the capacitor.

4. The ballast of claim 2, further including an additional inductor and a resistor serially connected to the capacitor.

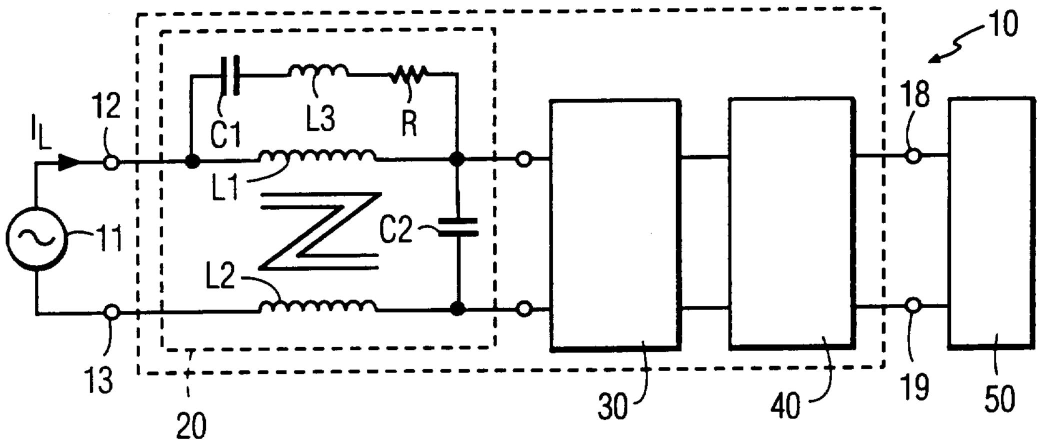
5. A method of operating a ballast having a ballast input, a ballast input impedance Z_{IN} as measured the across the ballast input and a filter coupled to the ballast input, having a filter output and characterized by an equivalent impedance Z_{eg}, comprising the steps of:

receiving at the ballast input from a utility power line under nominally rated ballast load conditions an alternating current having a peak amplitude;

drawing the alternating current through the filter, the filter further including an inductor having a core and a capacitor, the capacitor being coupled to at least a portion of the inductor and one of the filter output and ballast input, the core being substantially characterized by one B-H curve having a substantially linear region and a substantially non-linear region with a substantially uniform flux density existing throughout the core when in

the non-linear region;
maintaining the core within the non-linear region of its B-H core when at least at the peak amplitude of the alternating current under nominally rated ballast load conditions, characterized by
varying the relationship between the equivalent impedance Z_{eq} and the ballast input impedance Z_{IN} under nominally rated ballast load conditions such that $0.5 \leq Z_{eq}/Z_{IN} \leq 1.5$.

6. The method of claim 5, further including the step of filtering harmonics by passing a portion of the harmonics through the capacitor.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I_L
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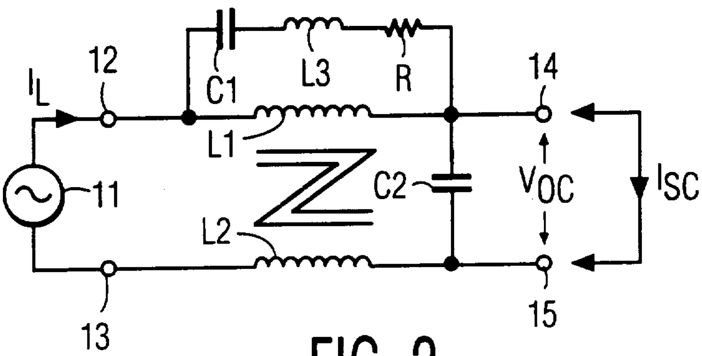
C1
L3
R
18
L1
11
C2
L2
13
20
30
40
19
50

FIG. 1


I_L
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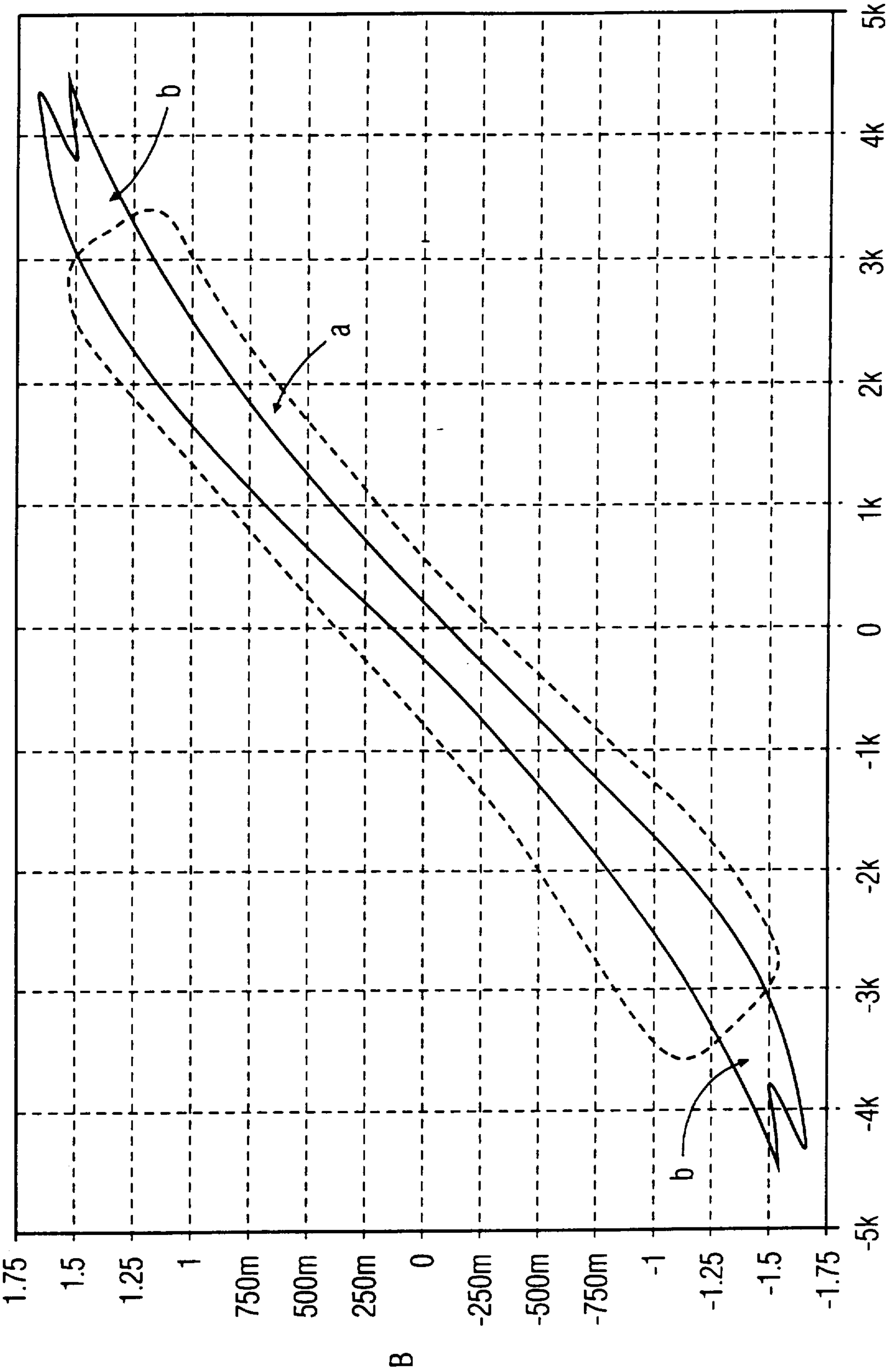
C1
L3
R
14
L1
11
C2
V_{OC}
I_{SC}
L2
13
15

FIG. 2

FIG. 3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1.5
1.25
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250m
0
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-500m
-750m
-1
-1.25
-1.5
-1.75
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-3k
-2k
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1k
2k
3k
4k
5k
a
b
b

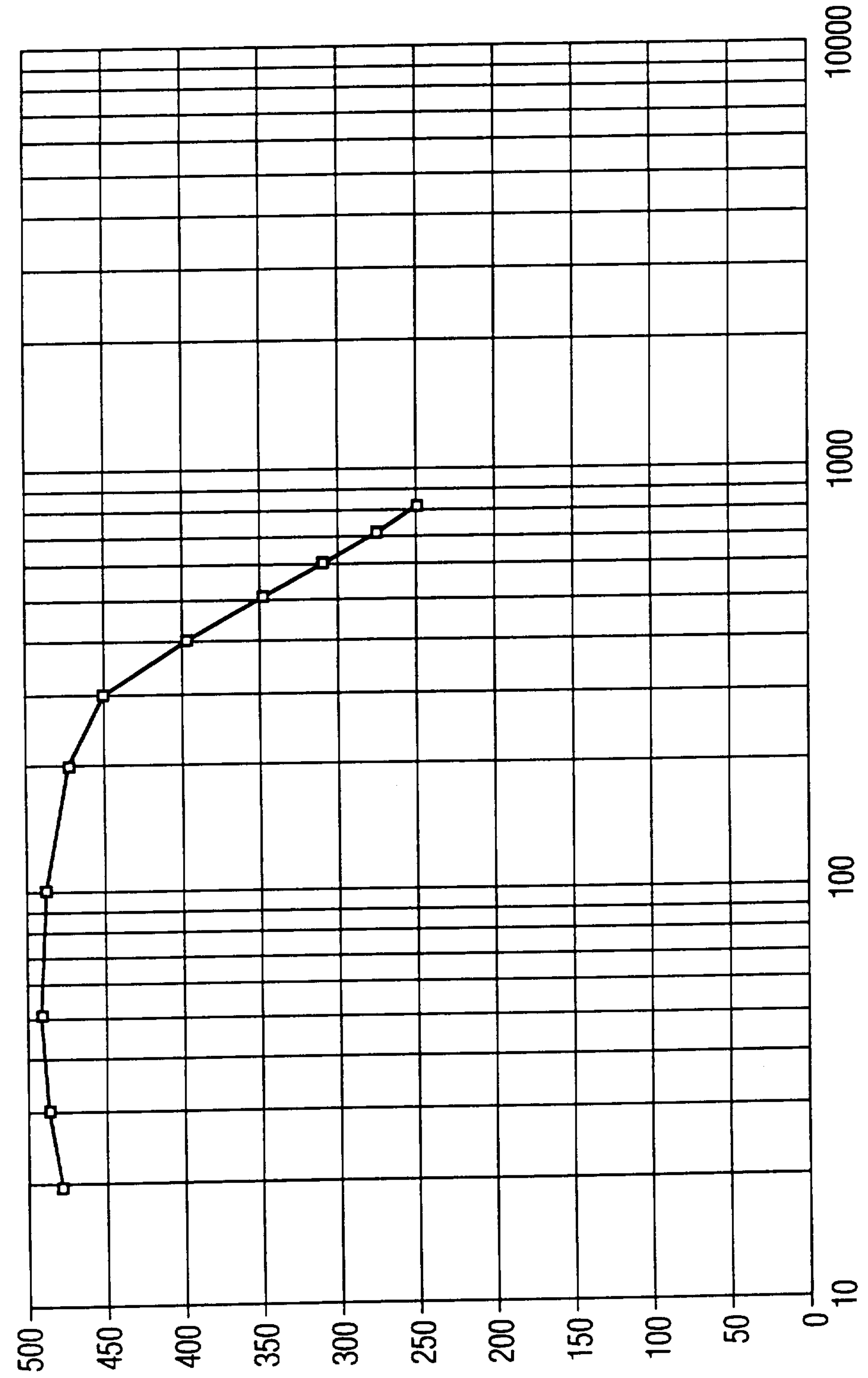

FIG. 4

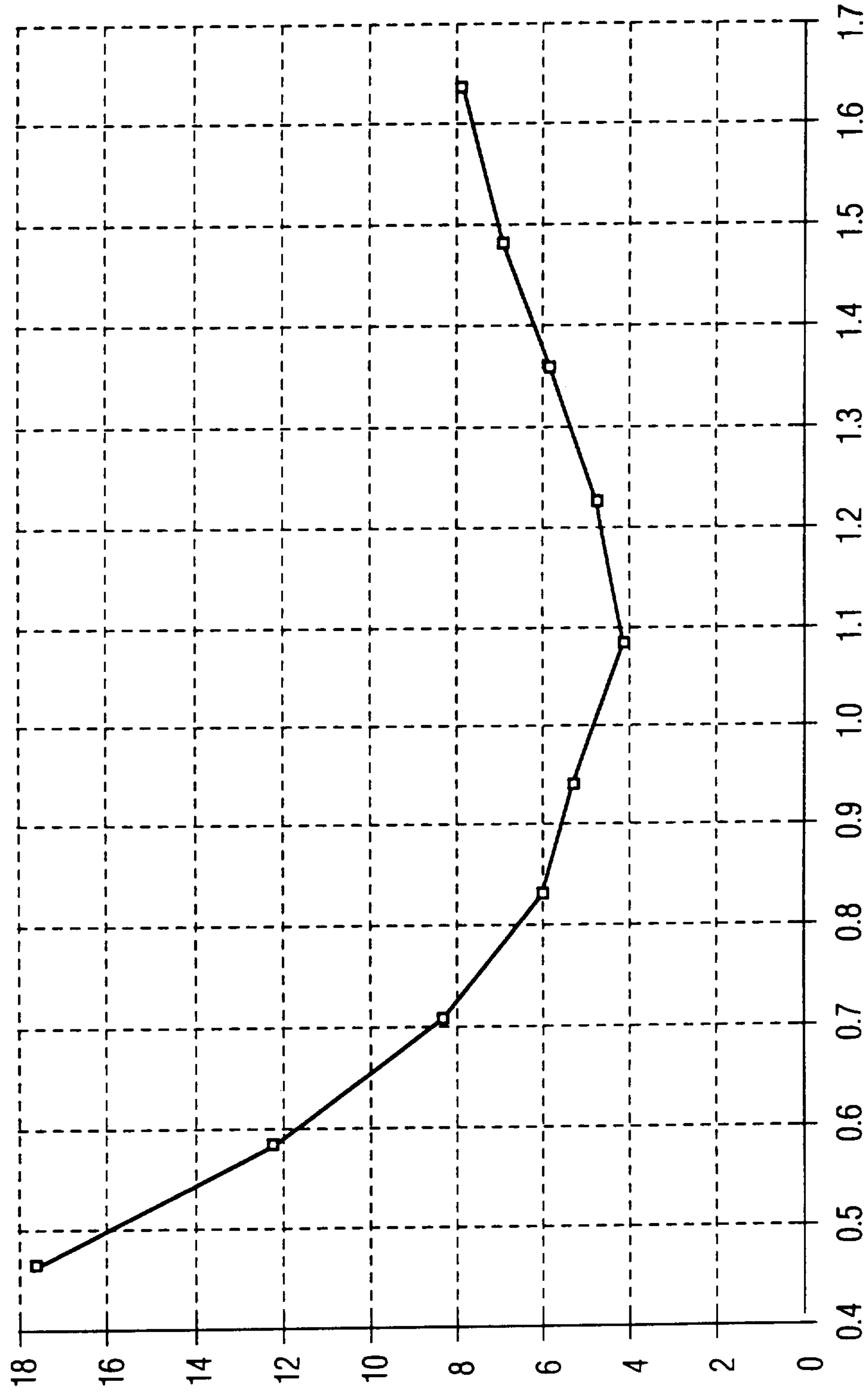

FIG. 5

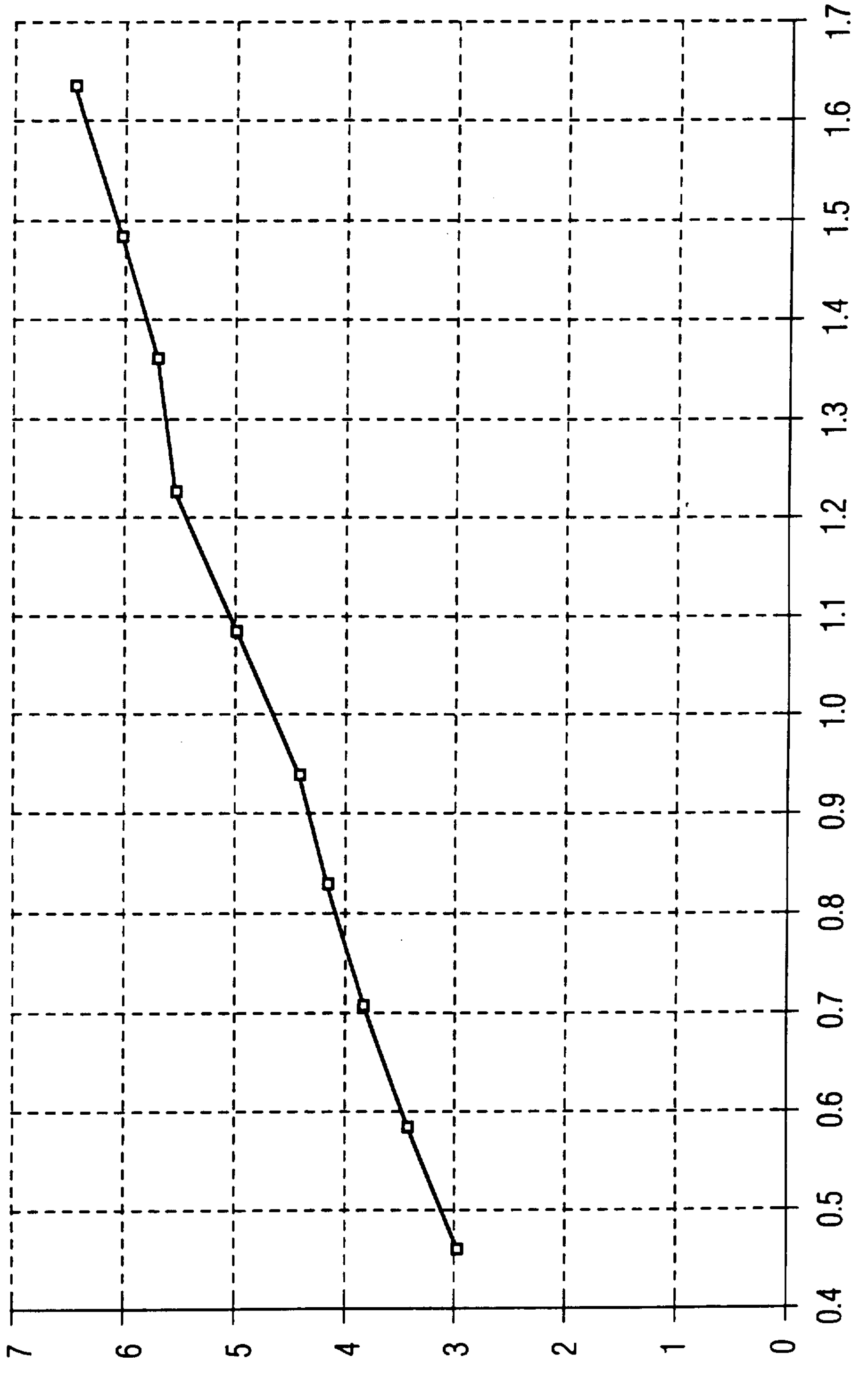

FIG. 6