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Fortsættes ...

DESCRIPTION

FIELD OF THE INVENTION

[0001] This invention relates to wind turbines and more particularly to methods and systems for monitoring the insulating state of their generator windings.

BACKGROUND (amendment included)

[0002] In order to maximize energy production and avoid unscheduled stops in large plants producing electricity there are different techniques and systems for assessing the insulation state of their generator. These technique and/or systems use special equipment so that when facing an incipient failure in the generator electrical insulation an appropriate corrective maintenance can be programmed.

[0003] As in other industrial sectors, in the wind industry would be advisable to monitor the insulation state of generators to avoid the negative consequences that occur in case of failure. In a wind turbine a failure in the generator insulation makes necessary a replacement thereof due to the difficulty for carrying out its on-site repair. Furthermore, in the case of wind power, wind turbines are often installed in places far from an industrial environment and, thus, a generator replacement involves a long repair time and a considerable loss of energy produced.

[0004] US2013/054043 discloses a fault detection system including a generator, a power converter, a breaker, a current monitoring device, and a control mode to detect a fault when the breaker is in the open position.

[0005] EP2541217A1, EP2851698A1 and US2010277137 disclose a method for identifying a fault in an electrical machine. EP2565658 discloses method for detecting mechanical faults in wind turbine generator.

[0006] However the techniques used for assessing the generator insulation state in other industrial sector such as, for example, the electrical generators of conventional thermal or hydroelectric plants are not applicable to wind turbines. The reason is that conventional plants are equipped with a generator of high power, for example 50MVA and above, while a wind farm of the same power can be formed by several wind turbines with generators having a power lesser than 10MVA. Therefore, to detect generator insulation faults in a wind farm, a fault detection system should be installed in each generator increasing significantly the system cost.

[0007] In other words, those methods that require the use of specific equipment to monitor the status of each generator in a planned manner throughout its lifetime are not profitable in the

wind industry.

[0008] It would be, therefore, desirable for the wind industry methods and systems specifically designed to detect insulation failures of wind turbine generators not needing to incorporate additional elements for that task as well as to their integration into existing wind turbines so that their cost is not increased.

[0009] The present invention is directed to the attention of these demands.

SUMMARY OF THE INVENTION

[0010] In one aspect, the invention provides a method for detecting faults in the insulation of a generator of a wind turbine coupled to an electrical network via a converter and provided with means for measuring electrical variables of the generator (voltage and current in rotor and stator) as well as their radial-horizontal and radial-vertical vibrations in the coupling side and in the opposite side to it.

[0011] The method comprises the following steps: a) capturing in real-time, during a predetermined time period (in situations where the generator is synchronized to the electrical network but is not yet coupled thereto as well as in situations where the generator is producing energy) the values of one or more generator electrical variables and the values of the generator radial-horizontal and radial-vertical vibrations in at least one of its two coupling sides; b) obtaining in real-time, the temporal evolution of the inverse values of said electrical variables at one or more predetermined frequencies and the temporal evolution of the values of said vibrations at one or more predetermined frequencies; c) identifying a possible generator insulation fault when the inverse value of at least one electrical variable and one of said vibrations at a predetermined frequency exceeds an absolute threshold or a temporal increase threshold pre-sets.

[0012] Embodiments of the method for different types of generator (doubly fed, permanent magnet and squirrel cage) in the mentioned coupling situations to the electrical network are envisaged and the relevant variables and predetermined frequencies for each of them are described.

[0013] In another aspect, the invention provides a system for implementing said method comprising a computer system connected to the data bus of the wind turbine for capturing the measures of the electrical variables (which can be provided by the converter or by a separate device thereof) and of the vibration variables provided by a measurement device connected to a set of sensors arranged on the generator.

[0014] Other characteristics and advantages of the present invention will be clear from the following detailed description of embodiments illustrative of its object in relation to the attached figures,

BRIEF DESCRIPTION OF THE FIGURES

[0015]

Figure 1 shows a Fast Fourier Transform containing the reverse (or negative) and direct (or positive) sequence of the stator voltage of a doubly fed wind-powered generator illustrating fault cases with a rhombus and cases without failure with a circle.

Figure 2a is a diagram showing the temporal evolution of the inverse component of the stator voltage of a doubly-fed wind-powered generator at -50Hz and Figure 2b is the same diagram indicating the absolute threshold and the temporal increase threshold used as fault indicators.

Figure 3 is a diagram showing comparatively the vibration components of a doubly fed wind-powered generator illustrating fault cases with a rhombus and cases without failure with a circle.

Figure 4 is a schematic diagram of the fault detection system in the insulation of a wind-powered generator according to the invention.

Figures 5 and 6 are schematic diagram of two embodiments of the fault detection system in the insulation of a permanent magnets wind-powered generator according to the invention.

Figure 7 illustrates the position of radial-vertical and radial-horizontal vibration sensors arranged in a wind-powered generator on the coupling side (the generator shaft exit side) and on the opposite side to the coupling.

DETAILED DESCRIPTION OF THE INVENTION

[0016] The present invention provides methods and systems for detecting the state of the insulation of the windings of a wind turbine generator by means of a real-time monitoring of, on the one hand, electrical variables and, on the other hand, its vibration, thereby enabling performing preventive maintenance work to avoid catastrophic failures in the generator insulation.

[0017] It has been noted in this regard that an insulation fault in the generator produces an imbalance in their voltages and currents in the rotor and in the stator leading to an increase in the inverse component of said variables particularly at certain frequencies.

[0018] For example, when analysing the reverse and the direct sequence of the stator voltage of a doubly fed generator (see Figure 1) it can be seen that failure occurs when the inverse component of the stator voltage at -50Hz stator reaches a certain value.

[0019] The monitoring of electrical variables proposed by the invention involves three steps:

- Capturing in real-time, during a predetermined time period, measurements of the values of one or more electrical variables of the generator (which, as discussed below, can be performed in the converter by which the generator is coupled to the electrical network or in a specific device separated from it).
- Obtaining in real time, from the measurements of voltage and/or current in the rotor and/or stator of the generator, the temporal evolution of the inverse components of one or more electrical variables at one or more predetermined frequencies where it is considered that there may be a fault in the generator. Following the case shown in Figure 1, once it has been identified that in a doubly fed generator a failure occurs in the inverse component of the stator at -50Hz, the temporal evolution of said variable must be obtained. As shown in Figure 2a the value of the inverse component of the stator voltage at -50Hz increases over time depending on the severity of the short-circuit.
- Identifying a possible insulation fault in the generator when the inverse component of, at least, one electric variable at a given frequency exceeds an absolute threshold or a temporal increase threshold pre-sets. Following the example of Figure 2a and as illustrated in Figure 2b such a possibility of failure would be identified when:
 1. a) The absolute threshold U_a of the inverse component of the stator voltage reaches the value of 10V.
 2. b) The temporal increase threshold U_{it} reaches a pre-set value. This value would be reached when the inverse component of the stator voltage reaches the value of 5v as in the range 2.5- 5v the derivative of the function representing the temporal evolution of the inverse component of the stator voltage reaches high values.

[0020] It has also been found that an imbalance of currents caused by a fault in the insulation produces an electromagnetic imbalance that will result in vibration of the generator at a certain frequency. For example, when analysing the evolution of the vibration of a doubly-fed generator of 11 kW it can be seen (see Figure 3) that there is an increase of vibration at 100Hz and 200Hz (2 and 4 times the frequency of a 50 Hz electrical network) when there is an incipient short-circuit in the generator stator.

[0021] The monitoring of the vibration proposed by the invention involves three similar steps to those of the electrical variables:

- Capturing in real-time, during a predetermined time period, measurements of the radial-horizontal vibration and the radial-vertical vibration of the generator on the side of the coupling to the electrical network and on the side opposite to it which, as will be discussed below, are performed by vibration measuring means incorporated to the generator such as those described in EP 1 531 376 B1.

- Obtaining in real-time, from these measurements, the temporal evolution of said vibrations at one or more predetermined frequencies where it is considered that there may be a fault in the generator.
- Identifying a possible insulation fault in the generator when at least one of said vibrations at a certain frequency exceeds an absolute threshold or a temporal increase threshold pre-sets.

[0022] Once identified a possible insulation fault because any one of the electrical or vibration mentioned variables exceeds any of the above mentioned thresholds appropriate corrective measures would be activated.

[0023] Said monitoring will be performed in time periods corresponding to low wind situations in which the generator is synchronized to the electrical network but not coupled thereto and in energy production periods.

[0024] In the first case, the objective is to verify the correct state of the insulation before coupling to the electrical network. This will prevent coupling the generator to the electrical network in case of significant loss of insulation and also minimizing the damages occurring in the generator in case of an outright short circuit. Damage or fatigue to other components will be also prevented as high currents or pairs of high short-circuits especially in double-fed generators are avoided. Checking the state of insulation in low wind situations is more effective as both transient events produced in the electrical network and unexpected wind gusts may cause erroneous measurements. Consequently, insulation faults can be detected in more incipient stages, because the lack of transient events allows refining the detection system.

[0025] In the second case, the objective is to detect loss of insulation in operation. In this case the generator can be stopped and the condition of the insulation in the previous mode be checked.

[0026] Following Figure 4 it can be seen that the mentioned monitoring in a generator 11 of a wind turbine connected to an electrical network 15 via a converter 13 is performed in an external computer system 21 connected to the data bus 17 of the wind turbine to which its control system 19 is also connected.

[0027] The data bus 17 receives in real-time a data stream D1 of measurements of the mentioned electrical variables and a data stream D2 of measurements of the mentioned vibrations.

[0028] As illustrated in more detail in Figure 5 the data stream D2 of measurements of vibration is generated on a vibration measuring device 14 connected to a sensor assembly 12 arranged on the generator 11. This assembly may comprise (see Figure 7) sensors in the positions indicated by arrows F1 and F3 for measuring the radial-vertical vibration and by

arrows F2 and F4 for measuring the radial-horizontal vibration in, respectively, the coupling side of generator 11 and the side opposite.

[0029] Meanwhile, as illustrated in Figure 6, the data stream D1 can be generated in a measuring device 16 separated from the converter 13 and provided with means for measuring the electrical variables of generator 11,

[0030] The software of the computer system 21 would obtain in real-time the temporal evolution of the inverse component of the mentioned electrical variables and of the mentioned vibrations at the indicated frequencies from data streams D1, D2. Furthermore, through the analysis of their temporal evolution, it would identify a possible failure of the insulation of generator 11 when the value of the inverse component of an electric variable and/or the value of one of the mentioned vibrations of generator 11 exceeds any of the pre-set thresholds. Finally, it would execute the foreseen appropriate alarm and message measures so that when a possible insulation failure is detected appropriate corrective actions can be taken.

[0031] The computer system 21 can be used for monitoring the insulation condition of the generator of various wind turbines by accessing their data buses.

[0032] The system of the invention is thus applicable to wind turbines having means for supplying in real-time values of the mentioned variables to a computer system 21.

[0033] The specific variables to be monitored, depending on the type of generator and on the temporal period in which monitoring is performed, comprise one or more of the following.

A) Doubly fed generators

[0034]

a1) The inverse component of the stator voltage at one or more of the following frequencies: frequency of the electrical network, an integer multiple of the inverse component of the frequency of the electrical network, an integer multiple of the direct component of the frequency of the electrical network.

a2) The inverse component of the stator current at one or more of the following frequencies: frequency of the electrical network; an integer multiple of the inverse component of the frequency of the electrical network; an integer multiple of the direct component of the frequency of the electrical network (only when the generator is coupled to the network).

a3) The inverse component of the rotor voltage at one or more of the following frequencies at a given speed (a speed should be selected for processing the measurements at that speed because the fundamental frequency of the rotor varies with its rotation speed) fundamental frequency of the rotor; an integer multiple of the inverse component of the fundamental frequency of the rotor, an integer multiple of the direct component of the fundamental

frequency of the rotor.

a4) The inverse component of the rotor current at one or more of the following frequencies at a given speed (a speed shall be selected for processing the measurements at that speed because the fundamental frequency of the rotor varies with its rotation speed): fundamental frequency of the rotor; an integer multiple of the inverse component of the fundamental frequency of the rotor; an integer multiple of the inverse component of the frequency of the electrical network; an integer multiple of the direct component of the frequency of the electrical network; frequencies defined by the formula $\pm n f_{sw} \pm m f_{rotor}$, being n and m integer numbers, f_{sw} the switching frequency of the converter and f_{rotor} the fundamental frequency of the rotor.

a5) The vibrations mentioned at one or more of the following frequencies: frequencies multiple of the frequency of the electrical network; frequencies defined by the formula

$$f_{red} \left[\pm 1 + \frac{\pm g Q}{p} (1 - s) \right],$$

being f_{red} the fundamental frequency of the electrical network, g an integer, Q the number of slots of the stator or the rotor (two calculations must, thus, be performed: one for the stator and one for the rotor), p the number of pole pairs and s the slip of the generator (as the slip of the generator varies with the rotational speed, a speed shall be selected for processing the measurements at that speed).

B) Permanent magnet generators

[0035]

b1) The inverse component of the stator voltage at one or more of the following frequencies: fundamental frequency of the stator; an integer multiple of the inverse component of the fundamental frequency of the stator; an integer multiple of the direct component of the fundamental frequency of the stator,

b2) The inverse component of the stator current at one or more of the following frequencies: fundamental frequency of the stator; an integer multiple of the Inverse component of the fundamental frequency of the stator; an integer multiple of the direct component of fundamental frequency the stator, frequencies defined by the formula $\pm n f_{sw} \pm m f_{stator}$, being n and m integer numbers, f_{sw} the switching frequency of the converter and f_{stator} the fundamental frequency of the stator.

b3) The mentioned vibrations at one or more of the following frequencies: frequencies multiple of the frequency of the electrical network; frequencies defined by the formula

$$f_{stator} \left[\pm 1 + \frac{\pm g Q}{p} (1 - s) \right],$$

being f_{stator} the fundamental frequency of the stator, g an integer, Q the number of slots of the stator and p the number of pole pairs.

[0036] In the case where the permanent magnet generator is synchronized to the network but not coupled thereto only the values of electrical variables and vibration at a same rotation speed will be taken into account for the calculation, (i.e, the analysis will be carried out at iso-speed). In this case the generator does not inject active power to the network and pure reactive power is used for operating the generator.

[0037] When the generator is coupled to the network only the values of electrical variables and vibration at a same rotation speed and at a same power will be taken into account for the calculation (i.e. the analysis will be carried out at iso-speed and iso-power).

C) Squirrel cage generators

[0038]

c1) The inverse component of the stator voltage at one or more of the following frequencies: fundamental frequency of the stator; an integer multiple of the inverse component of the fundamental frequency of the stator; an integer multiple of the direct component of the fundamental frequency of the stator.

c2) The inverse component of the stator current at one or more of the following frequencies: fundamental frequency of the stator; an integer multiple of the inverse component of the fundamental frequency of the stator; an integer multiple of the direct component of fundamental frequency the stator; frequencies defined by the formula $\pm n f_{sw} \pm m f_{stator}$, being n and m integer numbers, f_{sw} the switching frequency of the converter and f_{stator} the fundamental frequency of the stator.

c3) The mentioned vibrations at one or more of the following frequencies: frequencies multiple of the frequency of the electrical network; frequencies defined by the formula

$$f_{stator} \left[\pm 1 + \frac{\pm g Q}{p} (1 - s) \right],$$

being f_{stator} the fundamental frequency of the stator, g an integer, Q the number of slots of the stator, p the number of pole pairs and s the slip of the generator.

[0039] In the case where the squirrel cage generator is synchronized to the network but not coupled thereto only the values of electrical variables and vibration at a same rotation speed will be taken into account for the calculation. (i.e. the analysis will be carried out at Iso-speed). In this case the generator does not inject active power to the network and pure reactive power is used for operating the generator.

[0040] When the generator is coupled to the network only the values of electrical variables and vibration at a same rotation speed and at a same power will be taken into account for the calculation (i.e. the analysis will be carried out at iso-speed and iso-power).

[0041] Although the present invention has been described in connection with various embodiments, it will be appreciated from the specification that various combinations of elements, variations or improvements therein may be made, and are within the scope of the invention as defined by the appended claims.

REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

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P a t e n t k r a v

1. Fremgangsmåde til detektering af fejl i isoleringen af generatoren (11) af en vindmølle, som er tilkoblet et elektrisk netværk (15) gennem en omformer (13),
5 hvor vindmøllen er forsynet med målemidler af de elektriske variabler for generatoren (11) og af dens radial-horisontale og radial-vertikale vibrationer på koblingssiden til det elektriske netværk og på den modstående side dertil, kendetegnet ved, at fremgangsmåden omfatter de følgende trin:
- at indfange i realtid, i et forudbestemt tidsrum, værdierne af en eller flere
10 elektriske variabler for generatoren og værdierne af de radial-vertikale og radial-horisontale vibrationer for generatoren i mindst en af de nævnte sider tilvejebragt af måleindretningerne;
 - at opnå i realtid den tidsmæssige udvikling af de inverse værdier af de elektriske variabler på en eller flere forudbestemte frekvenser og den tidsmæssige
15 udvikling af værdierne af vibrationerne på en eller flere forudbestemte frekvenser;
 - at identificere en mulig isoleringsfejl i generatoren, når den inverse værdi af mindst en elektrisk variabel og en af vibrationerne på en af den forudbestemte frekvens overstiger en absolut tærskelværdi eller forudindstillinger for en tærskelværdi for en tidsmæssig stigning.
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2. Fremgangsmåde ifølge krav 1, kendetegnet ved, at:
- generatoren er en dobbeltforsynet generator;
 - 25 - tidsrummet, hvor indfangningen af værdierne udføres, er en periode, hvor generatoren er synkroniseret med det elektriske netværk, men endnu ikke er koblet dertil;
 - den tidsmæssige udvikling af en eller flere af de følgende variabler opnås i realtid:
 - 30 a) den inverse værdi af statorspændingen på en eller flere af de følgende frekvenser: frekvens i det elektriske netværk; et heltalsmultiplum af den inverse værdi af frekvensen i det elektriske netværk; et heltalsmultiplum af den direkte komponent af frekvensen i det elektriske netværk;
 - b) den inverse værdi af rotorspændingen på en eller flere af de følgende frekvenser ved en given hastighed: rotorens grundfrekvens; et heltalsmultiplum
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af den inverse værdi af rotorens grundfrekvens; et heltalsmultiplum af den direkte komponent af rotorens grundfrekvens;

5 c) den inverse værdi af rotorstrømmen på en eller flere af de følgende frekvenser: rotorens grundfrekvens ved en given hastighed; et heltalsmultiplum af den inverse komponent af rotorens grundfrekvens ved en given hastighed; et heltalsmultiplum af den inverse komponent af frekvensen i det elektriske netværk; et heltalsmultiplum af den direkte komponent af frekvensen i det elektriske netværk; frekvenser defineret af formlen $\pm n f_{sw} \pm m f_{rotor}$, værende n og m , værende n og m heltal, f_{sw} switching-frekvensen af omformereren og f_{rotor} rotorens grundfrekvens;

10 d) de nævnte vibrationer på en eller flere af de følgende frekvenser: frekvenser multiple af frekvensen i det elektriske netværk; frekvenser defineret af formlen, $f_{red} \left[\pm 1 + \frac{gQ}{p} (1 - s) \right]$,

15 hvor f_{red} er grundfrekvensen i det elektriske netværk, g er et heltal, Q er antallet af slots af statoren eller rotoren, p er antallet af polpar, og s er generatorens slip.

3. Fremgangsmåde ifølge krav 1, kendetegn et ved, at:

20 - generatoren er en dobbeltforsynet generator;
 - tidsrummet, hvor indfangningen af værdierne udføres, er en periode, hvor generatoren er tilkoblet nettet og genererer effekt;
 - den tidsmæssige udvikling af en eller flere af de følgende variabler ved den samme effekt opnås i realtid:

25 a) den inverse værdi af statorspændingen på en eller flere af de følgende frekvenser: frekvens i det elektriske netværk; et heltalsmultiplum af den inverse værdi af frekvensen i det elektriske netværk; et heltalsmultiplum af den direkte komponent af frekvensen i det elektriske netværk;

30 b) den inverse værdi af statorstrømmen på en eller flere af de følgende frekvenser: frekvens i det elektriske netværk; et heltalsmultiplum af den inverse værdi af frekvensen i det elektriske netværk; et heltalsmultiplum af den direkte værdi af frekvensen i det elektriske netværk;

c) den inverse værdi af rotorspændingen på en eller flere af de følgende frekvenser ved en given hastighed: rotorens grundfrekvens; et heltalsmultiplum

af den inverse værdi af rotorens grundfrekvens; et heltalsmultiplum af den direkte komponent af rotorens grundfrekvens;

5 d) den inverse værdi af rotorstrømmen på en eller flere af de følgende frekvenser: rotorens grundfrekvens ved en given hastighed; et heltalsmultiplum af den inverse værdi af rotorens grundfrekvens ved en given hastighed; et heltalsmultiplum af den inverse værdi af frekvensen i det elektriske netværk; et heltalsmultiplum af den direkte værdi af frekvensen i det elektriske netværk; frekvenser defineret af formlen $\pm n f_{sw} \pm m f_{rotor}$, værende n og m heltal, f_{sw} switching-frekvensen af omformereren og f_{rotor} rotorens grundfrekvens;

10 e) de nævnte vibrationer på en eller flere af de følgende frekvenser: frekvenser multiple af frekvensen i det elektrisk netværk; frekvenser defineret af formlen, $f_{red} \left[\pm 1 + \frac{\pm g Q}{p} (1 - s) \right]$,

15 hvor f_{red} er grundfrekvensen i det elektriske netværk, g er et heltal, Q er antallet af slidser af statoren eller rotoren, p er antallet af polpar, og s er generatorens slip.

4. Fremgangsmåde ifølge krav 1, kendetegn et ved, at:

- generatoren er en generator med permanent magnet;

20 - ved anvendelse af værdier ved en given hastighed, når generatoren i det nævnte tidsrum er synkroniseret med det elektriske netværk (15), men endnu ikke koblet dertil, og værdier ved en given hastighed og ved en given effekt, når generatoren er koblet til det elektriske netværk (15), opnås den tidsmæssige udvikling af en eller flere af de følgende variabler i realtid:

25 a) den inverse værdi af statorspændingen på en eller flere af de følgende frekvenser: statorens grundfrekvens; et heltalsmultiplum af den inverse værdi af statorens grundfrekvens; et heltalsmultiplum af den direkte værdi af statorens grundfrekvens;

30 b) den inverse værdi af statorstrømmen på en eller flere af de følgende frekvenser: statorens grundfrekvens; et heltalsmultiplum af den inverse værdi af statorens grundfrekvens; et heltalsmultiplum af den direkte værdi af statorens grundfrekvens; frekvenser defineret af formlen $\pm n f_{sw} \pm m f_{stator}$, værende n og m heltal, f_{sw} switching-frekvensen af omformereren og f_{stator} statorens grundfrekvens;

c) de nævnte vibrationer på en eller flere af de følgende frekvenser: frekvenser multiple af frekvensen i det elektriske netværk; frekvenser defineret af formlen

$$f_{\text{stator}} \left[\pm 1 + \frac{\pm g Q}{p} (1 - s) \right],$$

hvor f_{stator} er statorens grundfrekvens, g er et heltal, Q er antallet af slots af statoren, og p er antallet af polpar.

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5. Fremgangsmåde ifølge krav 1, kendetegn et ved, at:

- generatoren er en burviklingsgenerator;

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- ved anvendelse af værdier ved en given hastighed, når generatoren i det nævnte tidsrum er synkroniseret med det elektriske netværk (15), men endnu ikke koblet dertil, og værdier ved en given hastighed og ved en given effekt, når generatoren (11) er koblet til det elektriske netværk, opnås den tidsmæssige udvikling af en eller flere af de følgende variabler i realtid:

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a) den inverse værdi af statorspændingen på en eller flere af de følgende frekvenser: statorens grundfrekvens; et heltalsmultiplum af den inverse værdi af statorens grundfrekvens; et heltalsmultiplum af den direkte værdi af statorens grundfrekvens;

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b) den inverse værdi af statorstrømmen på en eller flere af de følgende frekvenser: statorens grundfrekvens; et heltalsmultiplum af den inverse værdi af statorens grundfrekvens; et heltalsmultiplum af den direkte værdi af statorens grundfrekvens; frekvenser defineret af formlen $\pm n f_{\text{sw}} \pm m f_{\text{stator}}$, værende n og m heltal, f_{sw} switching-frekvensen af omformeren, og f_{stator} er statorens grundfrekvens og ligger mellem ± 1 kHz og ± 10 kHz;

25

c) de nævnte vibrationer på en eller flere af de følgende frekvenser: frekvenser multiple af frekvensen i det elektriske netværk; frekvenser defineret af formlen

$$f_{\text{stator}} \left[\pm 1 + \frac{\pm g Q}{p} (1 - s) \right],$$

, hvor f_{stator} er statorens grundfrekvens, g er et heltal, Q er antallet af slots af statoren, p er antallet af polpar, og s er generatorens slip.

30

6. System til detektering af fejl i isoleringen af generatoren (11) i en vindmølle, som er koblet til et elektrisk netværk (15) gennem en omformer (13), hvor vindmøllen er forsynet med målemidler af de elektriske variabler af generatoren

(11) og af dens radial-horisontale og radial-vertikale vibrationer på koblingssiden og på den modstående side dertil såvel som med et styresystem (19) og en databus (17), kendetegnet ved, at systemet omfatter et computersystem (21), der er forbundet med databussen (17) med en software, som er tilpasset til:

5

- at indfange i realtid i et forudbestemt tidsrum værdierne af en eller flere elektriske variabler af generatoren (11) og værdierne af de radial-vertikale og radial-horisontale vibrationer af generatoren (11) i mindst en af de nævnte sider tilvejebragt af måleindretningerne;

10

- at opnå i realtid den tidsmæssige udvikling af de inverse værdier af de elektriske variabler på en eller flere forudbestemte frekvenser og den tidsmæssige udvikling af værdierne af vibrationerne på en eller flere forudbestemte frekvenser;

15

- at identificere en mulig isolationsfejl i generatoren (11), når den inverse værdi af mindst en elektrisk variabel og en af vibrationerne på en af den forudbestemte frekvens overstiger en absolut tærskelværdi eller forudindstillinger for en tærskelværdi for en midlertidig stigning.

20

7. System ifølge krav 6, kendetegnet ved, at målemidlerne af de elektriske variabler for generatoren (11) er integreret i omformeren (13).

25

8. System ifølge krav 6, kendetegnet ved, at målemidlerne af de elektriske variabler for generatoren (11) er anbragt i en måleindretning (16), der er adskilt fra omformeren (13) og forbundet med databussen (17).

30

9. System ifølge et af kravene 6-8, kendetegnet ved, at:

- generatoren (11) er en dobbeltforsynet generator;

- tidsrummet, hvor indfangningen af værdierne udføres, er en periode, hvor generatoren (11) er synkroniseret med det elektriske netværk (15), men endnu ikke er koblet dertil;

- den tidsmæssige udvikling af en eller flere af de følgende variabler opnås i realtid:

- a) den inverse værdi af statorspændingen på en eller flere af de følgende frekvenser: frekvens i det elektriske netværk (15); et heltalsmultiplum af den inverse værdi af frekvensen i det elektriske netværk (15); et heltalsmultiplum af den direkte værdi af frekvensen i det elektriske netværk (15);
- 5 b) den inverse værdi af rotorspændingen på en eller flere af de følgende frekvenser ved en given hastighed: rotorens grundfrekvens; et heltalsmultiplum af den inverse værdi af rotorens grundfrekvens; et heltalsmultiplum af den direkte værdi af rotorens grundfrekvens;
- 10 c) den inverse værdi af rotorstrømmen på en eller flere af de følgende frekvenser: rotorens grundfrekvens ved en given hastighed; et heltalsmultiplum af den inverse værdi af rotorens grundfrekvens ved en given hastighed; et heltalsmultiplum af den inverse værdi af frekvensen i det elektriske netværk (15); et heltalsmultiplum af den direkte værdi af frekvensen i det elektriske netværk (15); frekvenser defineret af formlen $\pm n f_{sw} \pm m f_{rotor}$, værende n y m , værende n og
- 15 m heltal, f_{sw} switching-frekvensen af omformereren og f_{rotor} rotorens grundfrekvens;
- d) de nævnte vibrationer på en eller flere af de følgende frekvenser: frekvenser multiple af frekvensen i det elektriske netværk; frekvenser defineret af formlen,
- 20 $f_{red} \left[\pm 1 + \frac{gQ}{p} (1 - s) \right]$,
- hvor f_{red} er grundfrekvensen i det elektriske netværk, g er et heltal, Q er antallet af slots af statoren eller rotoren, p er antallet af polpar y s generatorens slip (11).
- 25 10. System ifølge et af kravene 6-8 kendetegnet ved, at:
- generatoren (11) er en dobbeltforsynet generator;
 - tidsrummet, hvor indfangningen af værdierne udføres, er en periode, hvor generatoren (11) er tilkoblet nettet og genererer effekt;
 - den tidsmæssige udvikling af en eller flere af de følgende variabler ved den
- 30 samme effekt opnås i realtid:
- a) den inverse værdi af statorspændingen på en eller flere af de følgende frekvenser: frekvens i det elektriske netværk (15), et heltalsmultiplum af den inverse værdi af frekvensen i det elektriske netværk (15), et heltalsmultiplum af den direkte værdi af frekvensen i det elektriske netværk (15);

- b) den inverse værdi af statorstrømmen på en eller flere af de følgende frekvenser: frekvens i det elektriske netværk (15); et heltalsmultiplum af den inverse værdi af frekvensen i det elektriske netværk (15); et heltalsmultiplum af den direkte værdi af frekvensen i det elektriske netværk (15);
- 5 c) den inverse værdi af rotorspændingen på en eller flere af de følgende frekvenser ved en given hastighed: rotorens grundfrekvens; et heltalsmultiplum af den inverse værdi af rotorens grundfrekvens; et heltalsmultiplum af den direkte værdi af rotorens grundfrekvens;
- d) den inverse værdi af rotorstrømmen på en eller flere af de følgende frekvenser: rotorens grundfrekvens ved en given hastighed; et heltalsmultiplum af den inverse værdi af rotorens grundfrekvens ved en given hastighed; et heltalsmultiplum af den inverse værdi af frekvensen i det elektriske netværk (15); et heltalsmultiplum af den direkte værdi af frekvensen i det elektriske netværk (15);
- 10 frekvenser defineret af formlen $\pm n f_{sw} \pm m f_{rotor}$, værende n og m heltal, f_{sw} switching-frekvensen af omformereren og f_{rotor} rotorens grundfrekvens;
- 15 e) de nævnte vibrationer på en eller flere af de følgende frekvenser: frekvenser multiple af frekvensen i det elektriske netværk; frekvenser defineret af formlen
- $$f_{red} \left[\pm 1 + \frac{\pm g Q}{p} (1 - s) \right],$$
- , hvor f_{red} er grundfrekvensen i det elektriske netværk, g et heltal, Q antallet af slots af statoren eller rotoren, p antallet af polpar y s generatorens (11) slip.
- 20

11. System følge et af kravene 6-8, hvor:

- generatoren (11) er en generator med permanent magnet;
- 25 - ved anvendelse af værdier ved en given hastighed, når generatoren (11) i det nævnte tidsrum er synkroniseret med det elektriske netværk (15), men endnu ikke koblet dertil, og værdier ved en given hastighed og ved en given effekt, når generatoren (11) er koblet til det elektriske netværk (15), opnås den tidsmæssige udvikling af en eller flere af de følgende variabler i realtid:
- 30 a) den inverse værdi af statorspændingen på en eller flere af de følgende frekvenser: statorens grundfrekvens; et heltalsmultiplum af den inverse værdi af statorens grundfrekvens; et heltalsmultiplum af den direkte værdi af statorens grundfrekvens;
- b) den inverse værdi af statorstrømmen på en eller flere af de følgende frekvenser: statorens grundfrekvens; et heltalsmultiplum af den inverse værdi af
- 35

statorens grundfrekvens; et heltalsmultiplum af den direkte værdi af statorens grundfrekvens; frekvenser defineret af formlen $\pm n f_{sw} \pm m f_{stator}$, værende n og m heltal, f_{sw} switching-frekvensen af omformeren (13) og f_{stator} statorens grundfrekvens;

- 5 c) de nævnte vibrationer på en eller flere af de følgende frekvenser: frekvenser multiple af frekvensen i det elektriske netværk; frekvenser domineret af form-

$$f_{stator} \left[\pm 1 + \frac{\pm g Q}{p} (1 - s) \right],$$

10 , hvor f_{stator} er statorens grundfrekvens, g er et heltal, Q er antallet af slots af statoren, og p er antallet af polpar.

12. System ifølge et af kravene 6-8, kendetegnet ved, at:

- generatoren (11) er en burviklingsgenerator;

- 15 - ved anvendelse af værdier ved en given hastighed, når generatoren (11) i det nævnte tidsrum er synkroniseret med det elektriske netværk (15), men endnu ikke koblet dertil, og værdier ved en given hastighed og ved en given effekt, når generatoren (11) er koblet til det elektriske netværk (15), opnås den tidsmæssige udvikling af en eller flere af de følgende variabler i realtid:

- 20 a) den inverse værdi af statorspændingen på en eller flere af de følgende frekvenser: statorens grundfrekvens; et heltalsmultiplum af den inverse værdi af statorens grundfrekvens; et heltalsmultiplum af den direkte værdi af statorens grundfrekvens;

- 25 b) den inverse værdi af statorstrømmen på en eller flere af de følgende frekvenser: statorens grundfrekvens; et heltalsmultiplum af den inverse værdi af statorens grundfrekvens; et heltalsmultiplum af den direkte værdi af statorens grundfrekvens; frekvenser defineret af formlen $\pm n f_{sw} \pm m f_{stator}$, værende n og m heltal, f_{sw} switching-frekvensen af omformeren, og f_{stator} er statorens grundfrekvens og ligger mellem ± 1 kHz og ± 10 kHz;

- 30 c) de nævnte vibrationer på en eller flere af de følgende frekvenser: frekvenser multiple af frekvensen i det elektriske netværk; frekvenser defineret af formlen

$$f_{stator} \left[\pm 1 + \frac{\pm g Q}{p} (1 - s) \right],$$

hvor f_{stator} er statorens grundfrekvens, g er et heltal, Q er antallet af slots af statoren, p er antallet af polpar, og s er generatorens (11) slip.

DRAWINGS

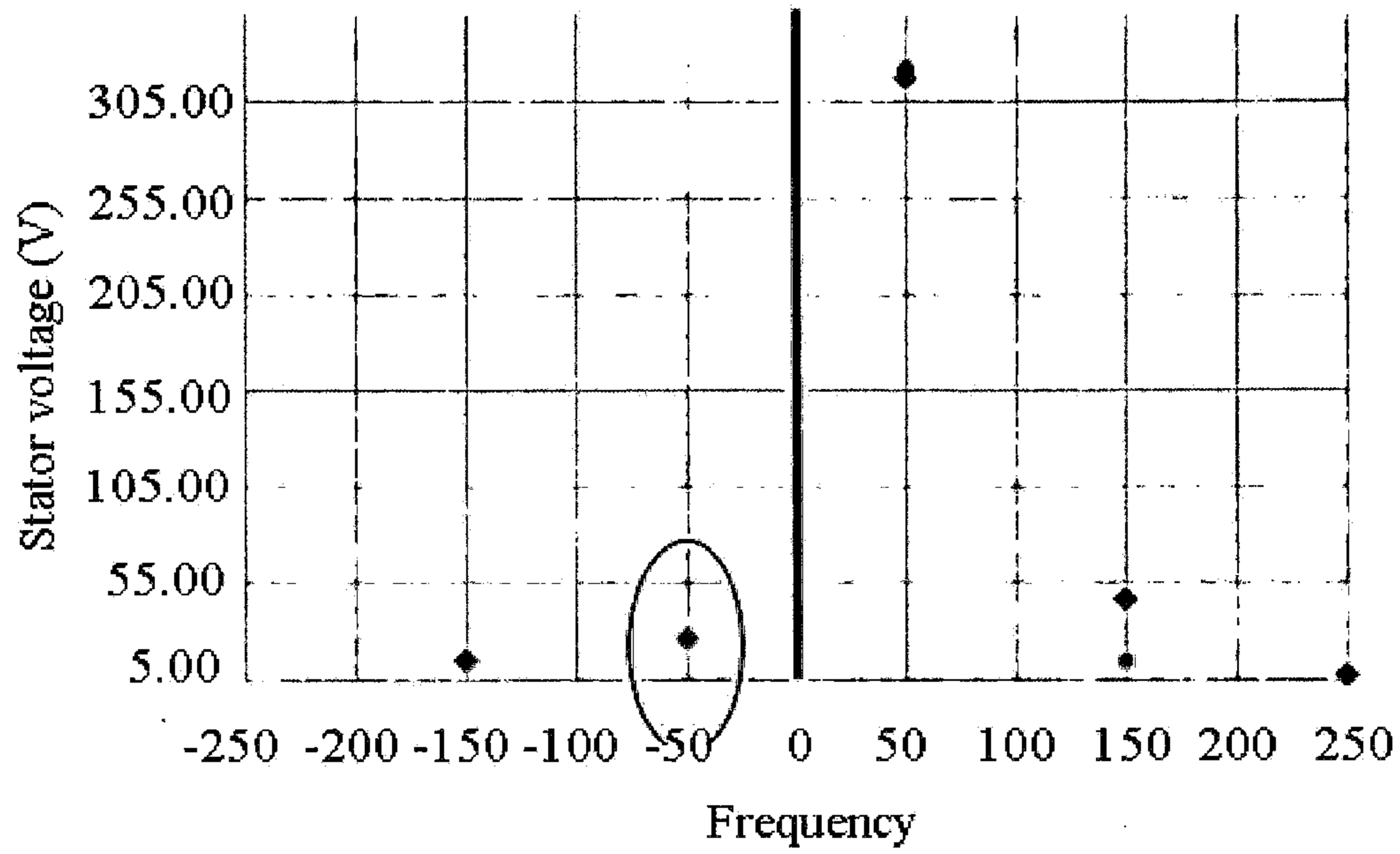


FIG. 1

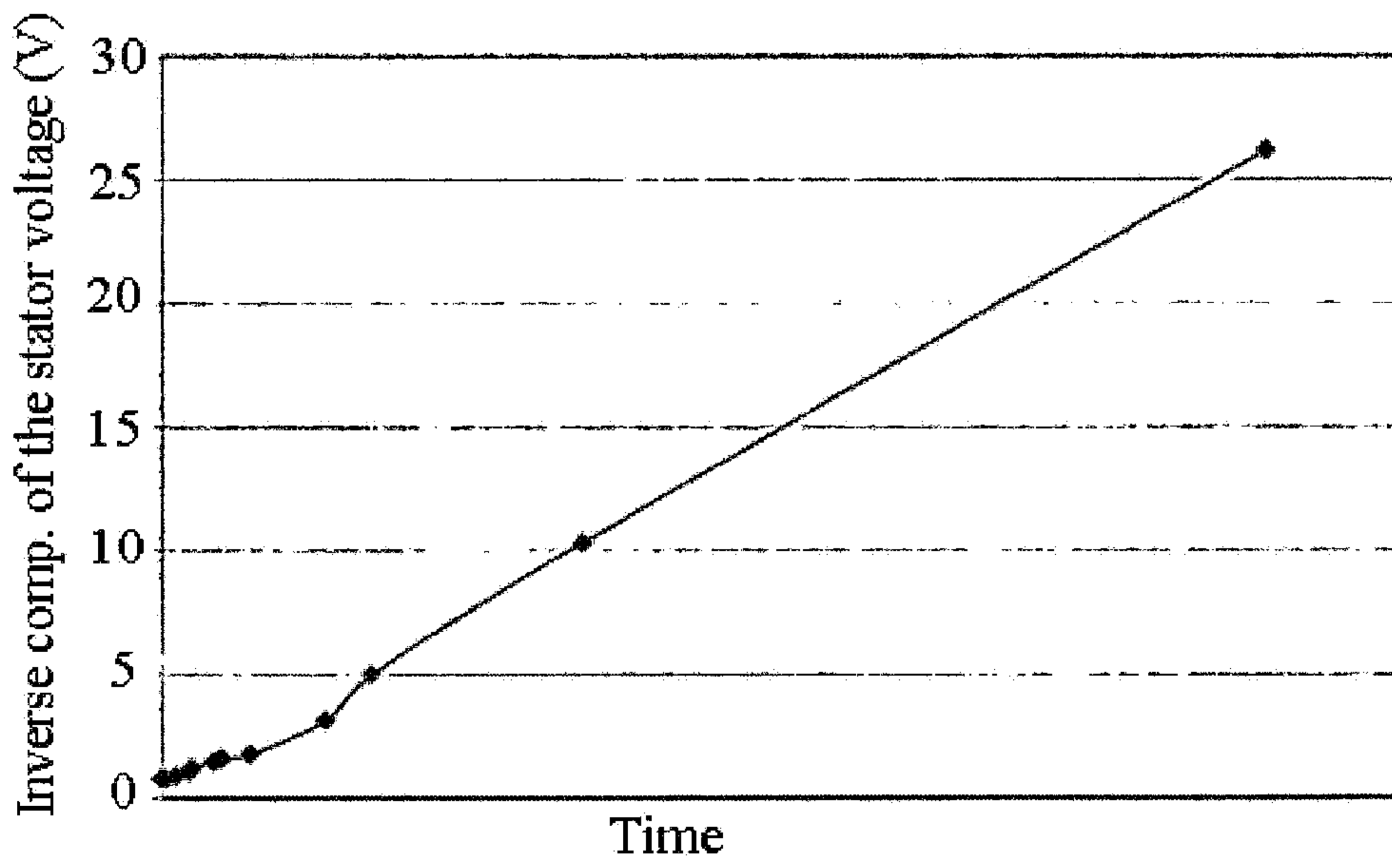


FIG. 2a

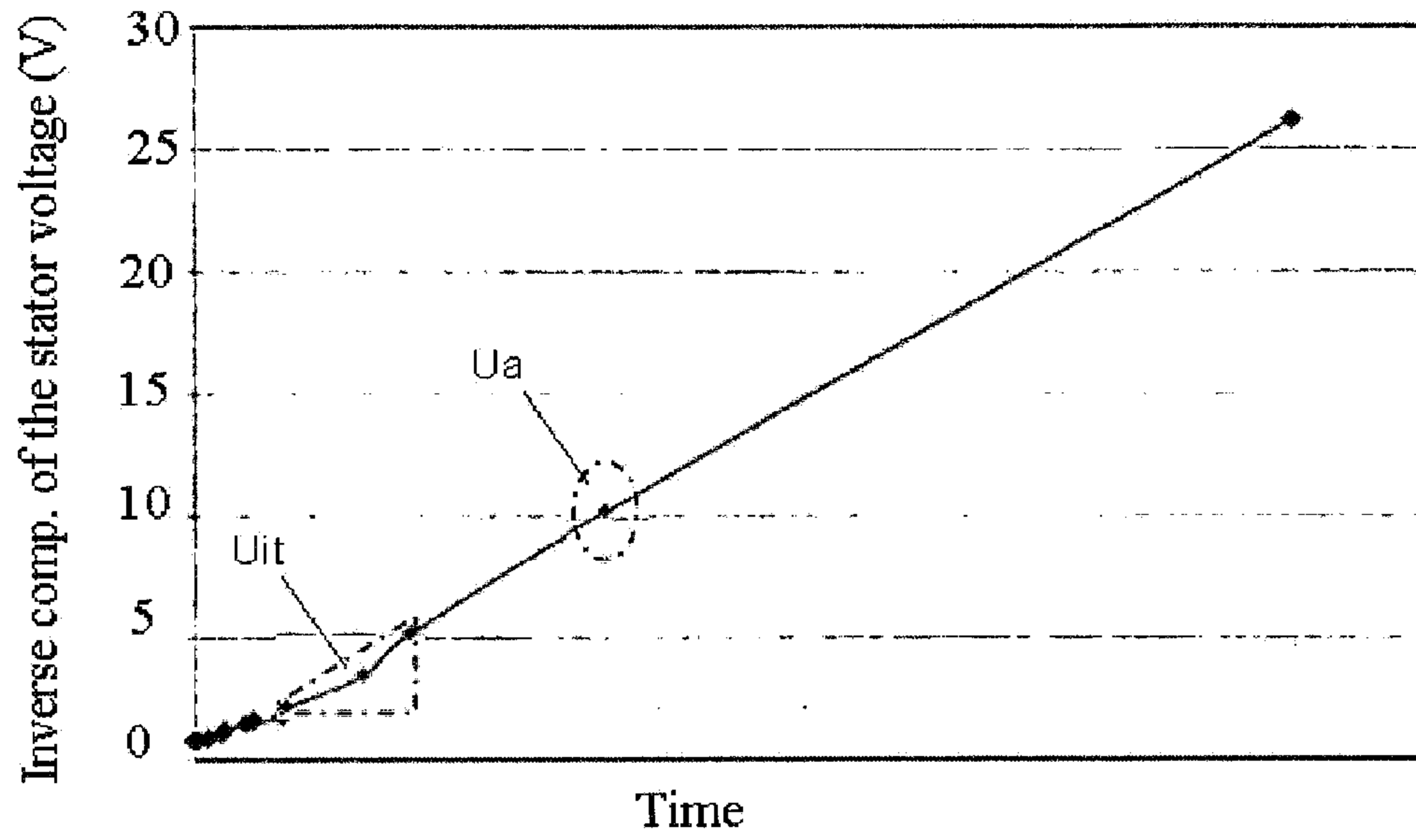


FIG. 2b

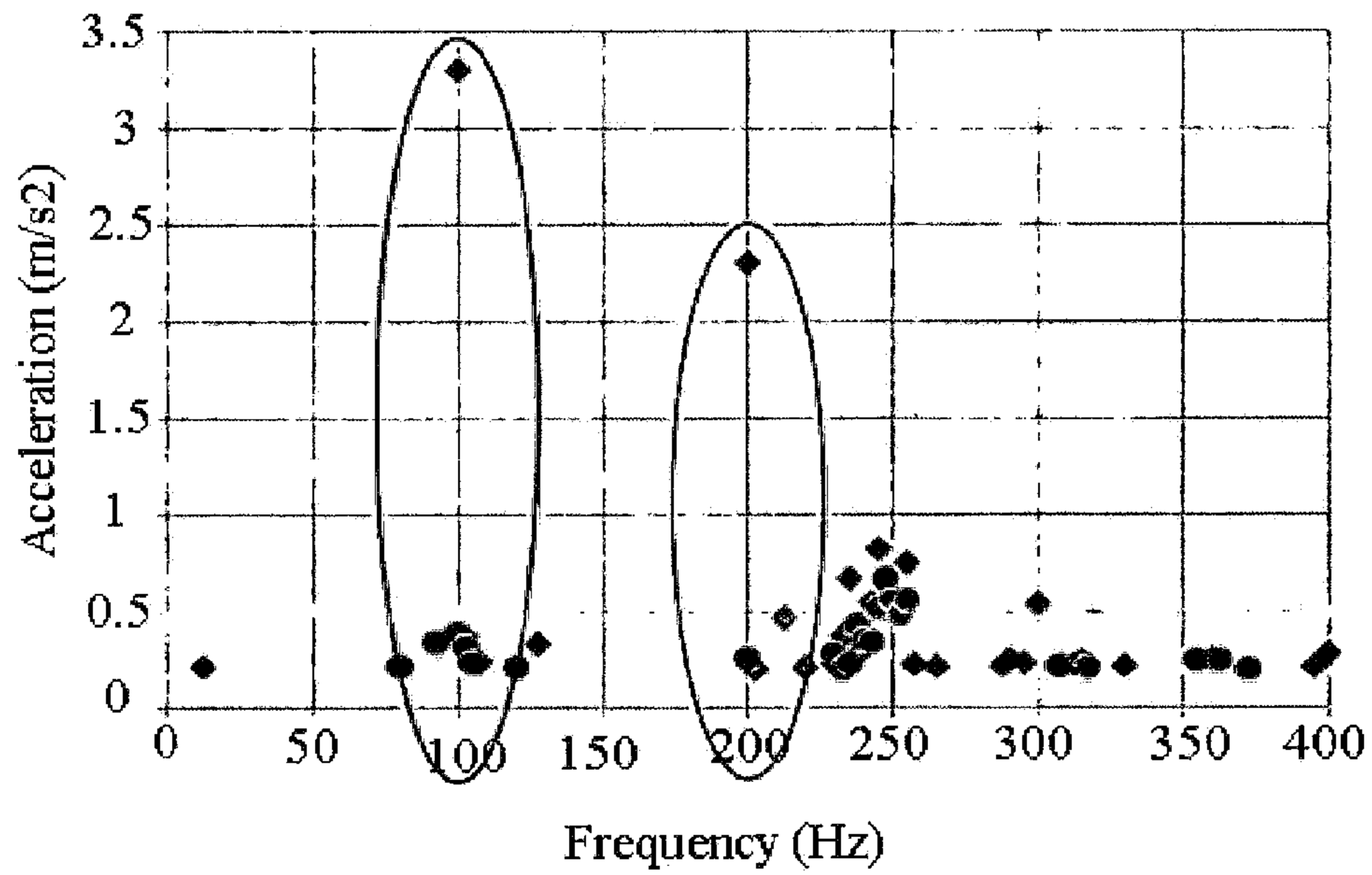


FIG. 3

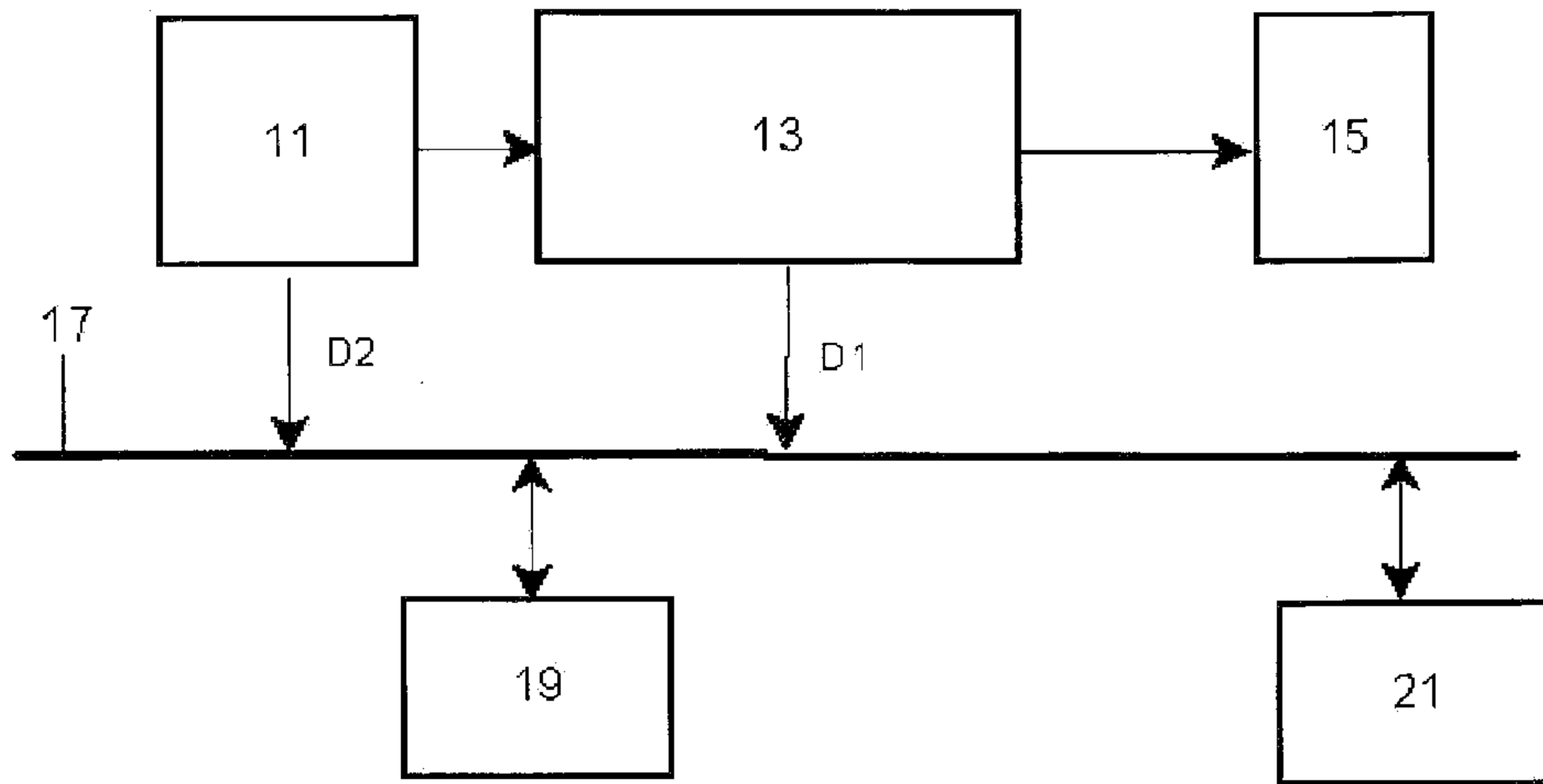


FIG. 4

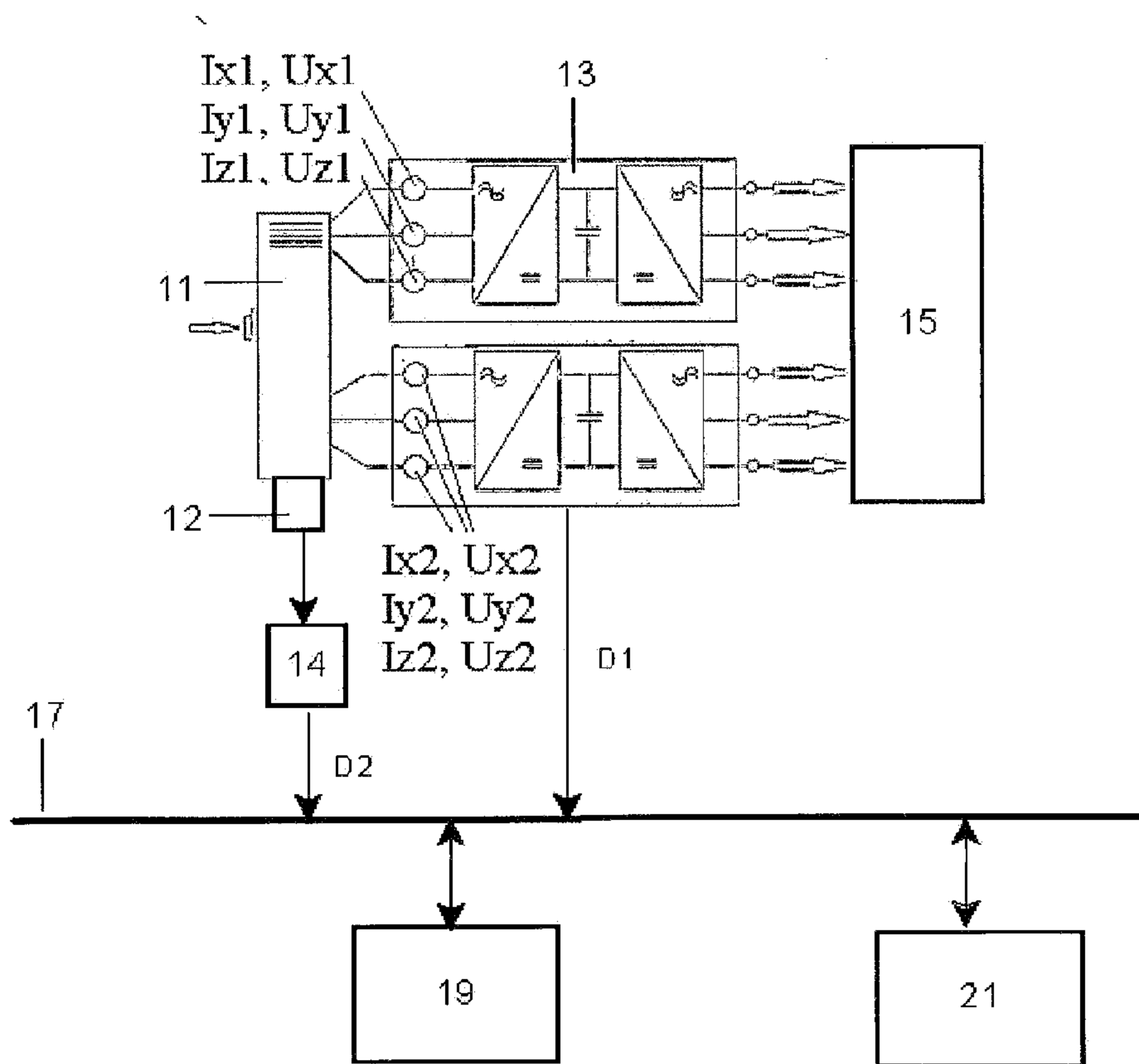


FIG. 5

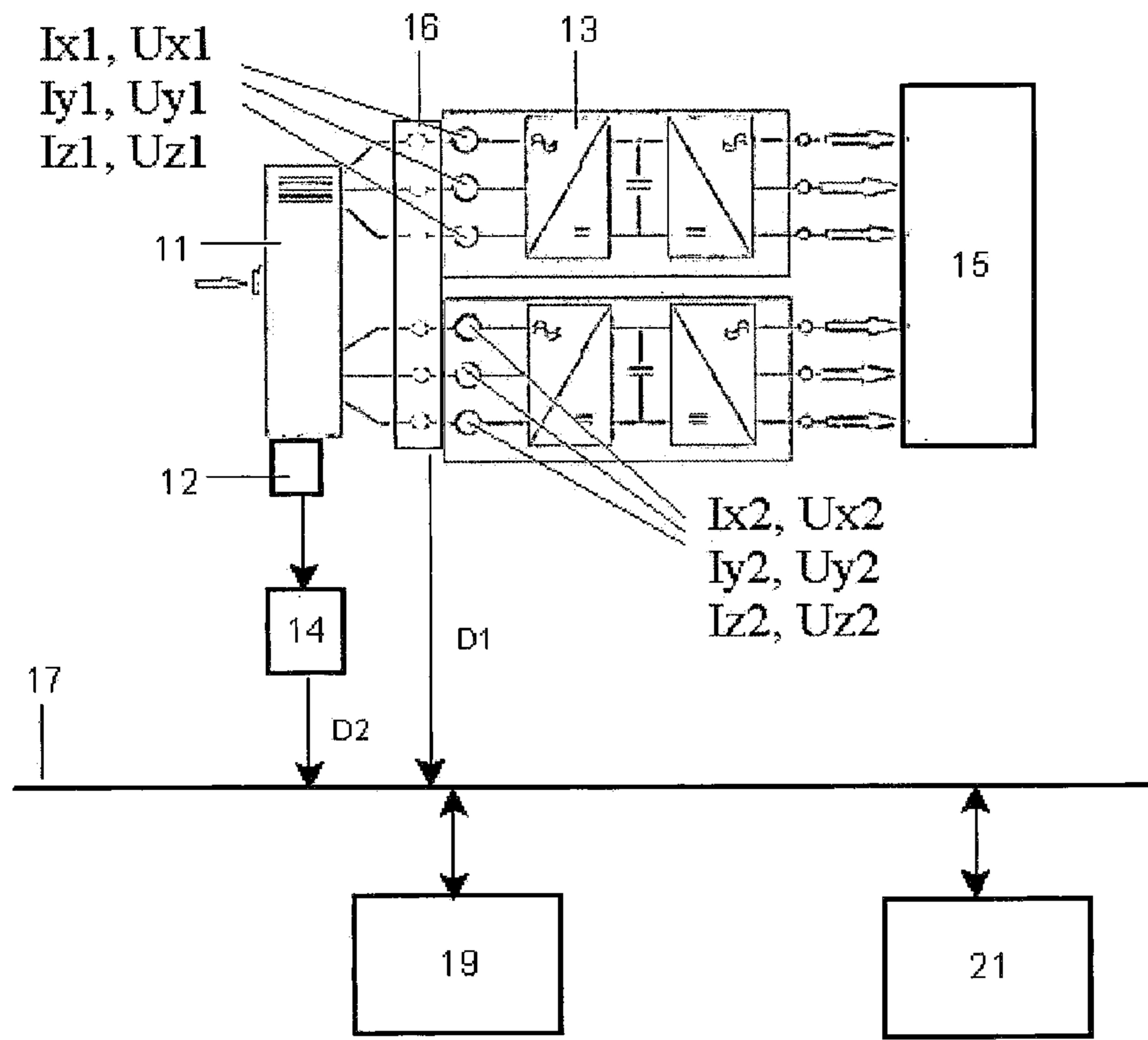


FIG. 6

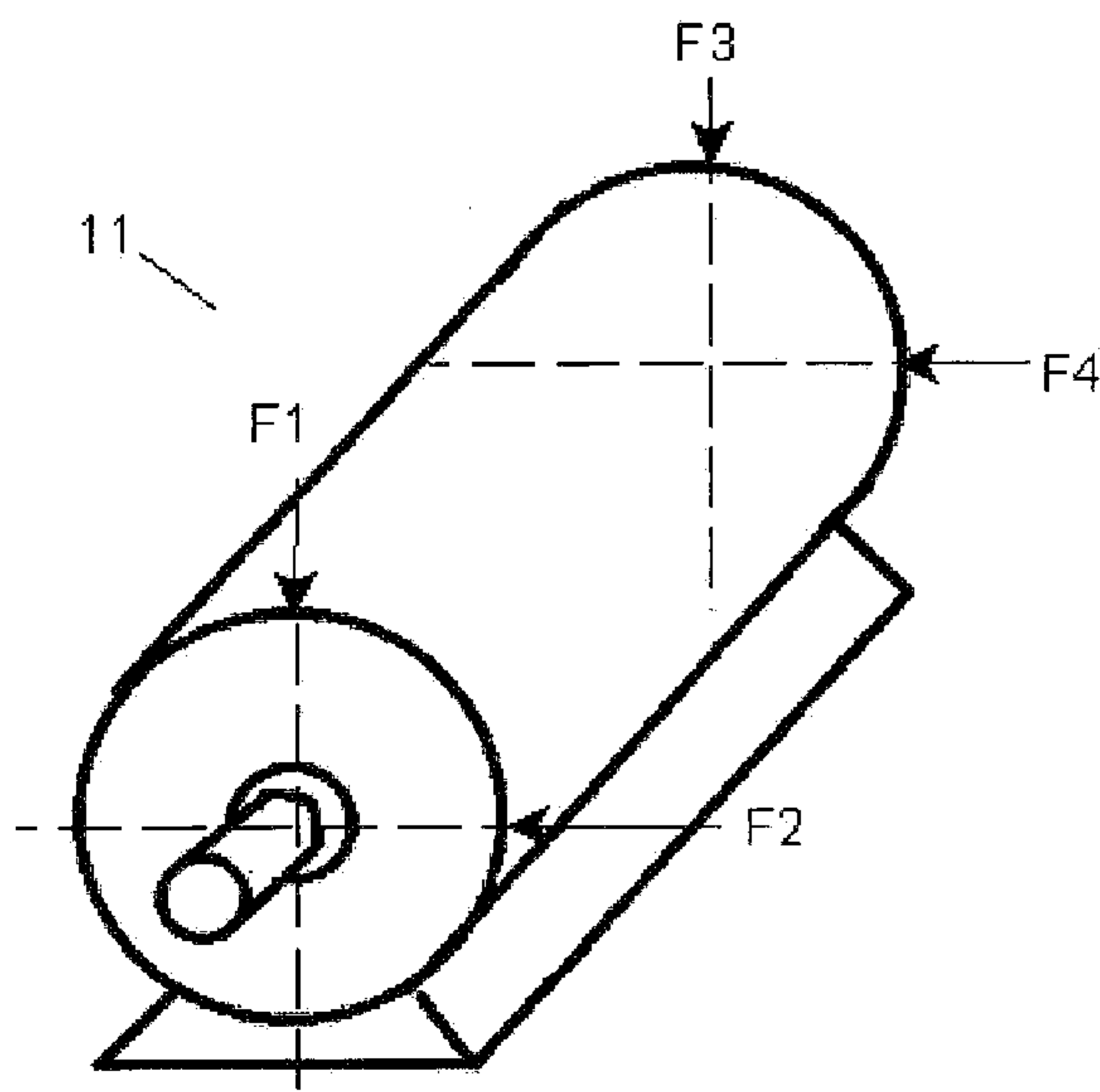


FIG. 7