



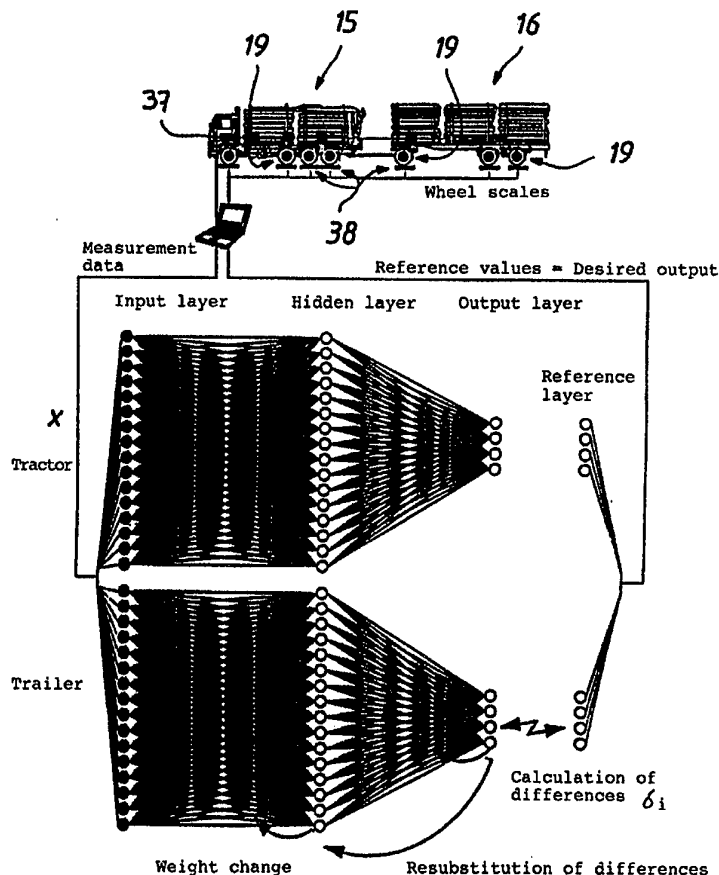
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(54) Title: METHOD FOR MEASURING LOADS BEING DIRECTED TO STRUCTURES

(57) Abstract

The invention relates to measuring loads directed to structures (1), and particularly to a method for measuring the weight of a vehicle. In the said method, detectors (6), particularly strain gauge detectors, measuring the deformation of the structures are attached to the frame parts (2) of the said structures, most advantageously in the vicinity of the points of support. According to the invention, the measurement signals obtained from the detectors (6) are preprocessed by means of a predetermined neural network, so that from the output layer of the network, there are obtained the loads directed to desired spots in the structures, and that the neural network is in advance trained with test loads to process the measurement signals from the said detectors.



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Method for measuring loads being directed to structures

The invention relates to a method according to the introductory part of patent claim 1 for measuring loads directed to structures. Structures here mean stationary
5 structures such as buildings, bridges, rails (railroads), quays, stationary load beds or the like, and moving structures, such as vehicles, hoisting gear and the like.

The invention also relates to a method according to the introductory part of patent claim 3 for measuring the weight of a vehicle. Vehicle here means a bed or space to be moved on wheels, runners or similar structures, on which bed or space for
10 instance gods and/or people can be transported, and which can be moved by its own power source or hauled, separately or in a combination, by a suitable hauling apparatus. The vehicle can be a car, for instance a truck, a railway vehicle, such as an engine or a railway car; a sleigh; a vehicle provided with one or several track chains, or even an airplane (being moved on wheels on the airfield), just to mention some
15 examples.

In the prior art there is known, from the international patent application PCT/FI91/00171 a method and apparatus for weighing a load. In this method, a load bed, such as a vehicle or a container, supported for instance by legs or wheels, is provided with detectors, advantageously strain gauge detectors, and the load weight
20 is defined on the basis of the signals obtained from these detectors. The said detectors are installed in the solid frame of the load bed, in the vicinity of the fastening points of the supports; they are used for measuring deformations and/or strain caused in the frame by the load, and the load weight is defined on the basis of these measurements.

25 A drawback with the above described method and apparatus is that the installation of the detectors at the points of measurement in the vicinity of the fastening points of support is mainly carried out experimentally, and hence it may be difficult to find the most suitable points of measurement in various load bed constructions.

In the prior art there is known, from the international patent application
30 PCT/FI94/00115 a method for weighing a load, introducing an efficient method for defining the points of measurement so that the detectors can be attached directly to advantageous measuring spots in connection with the load bed and thereafter calibrated, so that an essentially correct result, i.e. weight of the load, is obtained.

Thereby the drawbacks of the previously mentioned Finnish patent application can be avoided.

However, the problem with the latter method is that the points of measurement in the load bed are defined by a mathematical process which requires modeling of the load bed. This delays the application of the method, particularly in structures which have not been modeled before. Another drawback is the fact that the calibration of the detectors attached to the points of measurement is carried out straightforwardly by defining the correction factors on the basis of the loads of other points of support affecting each point. This arrangement becomes problematic, particularly when the number of the points of measurement grows and the measured load bed or other structure becomes complicated.

The object of the invention is to eliminate at least part of the above mentioned drawbacks and to simplify the method of measurement. A particular object of the invention is to introduce a new and efficient method for defining the load in various structures, so that the numbers of points of measurement and/or complexities of construction in the structure do not cause insurmountable difficulties when measuring the loads directed thereto.

The method of the invention for measuring loads directed to structures is characterized by the features stated in the novelty part of the patent claim 1.

The method of the invention for measuring the load of a vehicle is characterized by the features stated in the novelty part of the patent claim 3.

In the method of the invention for measuring loads directed to structures, the detectors measuring deformation in structures, advantageously strain gauge detectors, are attached to the frame parts of the structures, most advantageously in the vicinity of the support points. According to the invention, the measurement signals obtained from the detectors are processed by means of a predetermined neural network, so that from the output level of the network, there are obtained the loads directed to desired points of the structures, and that the neural network is in advance trained with test loads to process the measurement signals of the said measuring detectors.

In an advantageous method of the invention
- predetermined loads with known weights are arranged at the support points of the structures;

- the measurement signals obtained from the measuring detectors are preprocessed and considered as input signals from the input units of the input layer of the predetermined neural network;
- all measurement signals are processed in the neural network by using preliminary weights in between the units of the different layers of the neural network, so that the computational load values directed to the said support points of the structures are defined as output signals of the output units of the output layer;
- the values of known loads directed to the support points of the structures are compared with the computational load values, and on the basis of the difference of these values, there are defined new weights which replace the preliminary weights;
- all measurement signals are reprocessed in the neural network by using the new weights in between the units of different layers, so that the computational load values directed to the said support points of the structures are defined as output signals of the output units of the output layer of the neural network;
- the values of known loads directed to the support points of the structures are compared with the new computational load values and, if the difference surpasses the preset threshold values, on the basis of the difference of these values, there are again defined new weights, and the above described calculatory procedure is repeated; if the difference now remains within allowed limits, i.e. remains below the threshold value, the weights are retained;
- the predetermined loads arranged at the support points of the structures are removed; and
- by means of the measurement signals obtained from the measuring detectors connected to the points of support, the load directed to one or several points of support is defined by means of the neural network and the predetermined weights.

An advantage of the method of the invention is that it can be applied to many types of structures. These structures can be stationary, such as buildings, bridges, load beds and loading ramps, or movable, such as vehicles, trucks, hoisting gear or the like. The measuring system of the invention is particularly suited to observing variation in loads and to controlling and/or defining the distribution of loads in the different parts of the structures. The method can be used for detecting load peaks and for alarming when a preset load limit is surpassed, as a total load value and/or with respect to chosen structures. Yet another advantage of the invention is that the number of measuring points and/or desired measurement signals does not have to be limited. By applying the method of the invention, there can be processed a large number of measurement signals, on the condition that the measuring system is

provided with a sufficient data processing capacity, particularly calculatory capacity.

5 The most advantageous application of the invention relates to a method for measuring the load and/or load distribution of a vehicle. In this method, the detectors measuring the deformation of structures, particularly strain gauge detectors, are attached to the load-bearing parts of the vehicle, particularly to the frame parts, most advantageously in the vicinity of the support points. According to the invention, the measurement signals obtained from the measuring detectors are
10 processed by means of a predetermined neural network, so that from the output layer of the neural network there are obtained weight loads directed to desired spots of the vehicles, particularly to one or several points of support, and that the neural network is in advance trained with test loads to process the measurement signals from the said detectors.

15 It is an advantage of the weight measurement system of the invention that the measuring detectors can be attached to the frame beams of the vehicle, particularly a truck and/or a trailer, in the vicinity of the points of suspension or points of support of the wheels, to which support points the reaction forces are directed. As for the
20 definition of the load values, the locations of the measuring points/detectors do not have to be set at the theoretically exact optimum points, but it suffices that the gauges are located in the correct area. The correct area is dependent on the structure, and it is generally the area surrounding the support points of the structure; in the case of a truck, for instance, it is the area surrounding the wheels and/or wheel
25 bogies. Another advantage is that the number of the detectors does not have to be limited; around the fastening/support points, there can be arranged several strain gauge detectors or the like. Yet another advantage of the invention is that the measuring system applying the method is calibrated in connection with the installation of the system, whereafter it is in a fully operable order. If necessary,
30 check calibrations can still be carried out. Yet another advantage of the system is that by programmatic means, it is possible to define the distribution of weight with respect to wheels/wheel bogies particularly in trucks or the like and to control overweight, uneven distribution of the load, shifting of the load etc.

35 The invention is explained below with reference to the appended drawings, where Figure 1 is a schematic illustration of the beam structure;

- Figure 2 illustrates one junction A of the beams in the beam structure of Figure 1 as well as connected measuring detectors and the processing system of the measurement signals in block diagram form;
- Figure 3 illustrates a three-layered neural network for calculating the loads;
- 5 Figure 4 illustrates a processing unit, i.e. a neuron, of the neural network;
- Figures 5 and 6 illustrate in flowchart form the training process of the neural network, the said neural network being suited to the load measuring system;
- Figure 7 illustrates in flowchart form the measuring of the load carried out by means of the neural network;
- 10 Figure 8 is a schematic top-view illustration of a vehicle combination where in the frame of the tractor and the trailer, there are arranged detectors in order to measure the weight and/or weight distribution, and the obtained measurement signals are processed by a suitable data processing unit according to the method of the invention;
- 15 Figure 9 is a top-view illustration of a detail of the vehicle combination of Figure 8, i.e. depicted the fastening of the wheel to the frame structure of the vehicle and the installation of the measuring detectors in connection with the frame part;
- 20 Figure 10 is a side-view illustration of a detail of the vehicle combination of Figure 8 (cf. Figure 9); and
- Figure 11 illustrates how the measuring method of the invention is applied to the weight measuring system of the vehicle of Figure 8.
- Figure 1 illustrates a lattice-like steel beam structure 1, which forms for instance the frame of a building or part of the frame. The horizontal beams 2 of the steel beam structure 1 form one floor level or the like. The horizontal beams 2 are supported against the foundation 4 and/or to the preceding floor level by vertical beams 3, 3'.
- 25 The junction A of the horizontal and vertical beams 2, 3, 3' is illustrated in Figure 2. The junctions of the horizontal and vertical beams 2, 3, 3', such as the junction A, constitute the locations or support points, through which the weight load, among others, is directed to the various parts of the structure and is shifted in the structures.
- 30 In Figure 2, the horizontal beams 2; 2¹, 2², 2³ are suitably interconnected at the vertical beams 3, 3'. In this case the beams 2, 3, 3' are I-beams. In the vicinity of the vertical beam 3, 3', in connection with the horizontal beams 2; 2¹, 2², 2³, in the vertical web parts 5; 5¹, 5², 5³ thereof, there are attached the measuring detectors 6; 6¹, 6², 6³, 6⁴, 6⁵ and 6⁶.
- 35

The measuring detectors 6 are advantageously realized of two or more strain gauge elements arranged crosswise or at an angle with respect to each other. They are attached, for instance glued, onto the opposite sides of the web parts 5, on both sides of the beam 2, symmetrically at a suitable, advantageously calculated distance from the junction and support point A formed by the horizontal 2 and vertical 3, 3' beams. The locations of the points of measurement are defined for example by means of the known FEM (Finite Element Method), and the measuring detectors 6 are installed in an area which is suitable with respect to the theoretically calculated optimal point of measurement. The points of measurement are placed in the vicinity of the support points especially because on the basis of the difference of the shearing strengths affective on the different sides of the support points, it is possible to determine the support reactions, such as weight loads directed to the support points. By means of the detectors 6, there are measured deformations, such as bending and/or strain and compression in structures, in this case in the horizontal beams 2.

In connection with the vertical beams 3, 3' of the steel beam structure 1 of Figure 1, in this embodiment in the web parts 5; 5⁴, there can also be provided measuring detectors 6; 6⁷, 6⁸. In addition to the above described detectors 6; 6¹, 6², 6³, 6⁴, 6⁵, 6⁶, they can also be installed at each desired junction A; A1, A2, A3,... or alternatingly with respect to these. In the latter case, at the junction there is measured the compression directed to this support point, i.e. only vertical forces F, whereas in the former and more general case, all strains directed to the structures can be measured.

The measuring detectors 6, 6¹, 6², 6³, ..., 6^N (N = 1, 2, 3, ...) are connected to the preprocessing unit 7; 7¹, 7², 7³,...of each support point. In the preprocessing unit 7, the measurement signal obtained from the measuring detectors 6 is processed, for instance amplified and stabilized, in order to be suitable for the input interfaces of the successive processing units. From the preprocessing unit 7, the measurement signals are fed to the neural network unit 8 for the processing proper of the measurement signals. To the neural network unit 8, there are connected one or several memory units 9, a display unit 10 and keyboard 11. To the neural network unit 8 there are also connected the measurement signals obtained through the preprocessing units 7; 7¹, 7², ...from other measuring detectors 6 arranged at the respective support points in the structure 1. The neural network unit 8 advantageously constitutes a data processing unit including one or several microprocessors.

- The measurement signals are processed in the neural network unit 8 by means of a recorded neural network program, so that from the output layer of the neural network there are obtained as results the loads directed to desired points in the structure 1, for instance to one or several support points A; A1, A2, A3, The neural network unit 8, i.e. the neural network, can be considered to be composed of separate but interconnected calculatory or processing units. The neural network is trained in advance with test loads to process the measurement signals of the said measuring detectors.
- Figure 3 illustrates a three-layered neural network, which is a so-called perceptron network. Figure 4 illustrates a processing unit, i.e. neuron, of this type of neural network. The employed neural network is a network of three or more layers, comprising an input layer 12, one or several hidden layers 13 and an output layer 14. Let us now suppose that the analogous measurement signals x ; x_0 , x_1 , x_2 , x_3 obtained from the measuring detectors 6 are processed in the preprocessing unit 7, where they are normalized to the area $[0, 1]$ and digitized. The thus formed normalized input signals are fed to the neural network unit 8. Now the normalized input signals are fed into the input units 12^1 , 12^2 , 12^3 , 12^4 of the input layer of the neural network. The output signals V_0^0 , V_1^0 , V_2^0 obtained from these input units are formed by multiplying the normalized input signals by the first weights w_{jk}^1 , and the obtained products are summed in a predetermined fashion in the processing unit 13^1 , 13^2 of the hidden layer. The output signals V_0^1 , V_1^1 obtained from the processing units 13^1 , 13^2 of the hidden layer 13 are multiplied by the second weights w_{ij}^2 , and the obtained products are suitably summed in the processing units 14^1 , 14^2 , 14^3 of the output layer 14 in order to create the desired output signals y ; y_0 , y_1 , y_2 . Thereafter the output signals y are rescaled back to load or weight data (denormalization), which represents for instance loads directed to predetermined points A; A1, A2, A3,... in the structure 1.
- The operation of the neural network can be illustrated by observing the neuron of Figure 4. The input signal x , i.e. the input vector $\underline{x} = [x_0, x_1, x_2, x_3, \dots, x_{N-1}]^T$ is fed into the neural network, i.e. to each input or processing unit 12 ; 12^1 , 12^2 , 12^3 , 12^4 of the input layer 12. The element of each input vector \underline{x} is multiplied in the neuron by a weight w_i corresponding to the input signal. In principle the input signal can be either an analogous or a digital (binary) signal. The obtained weighted input signals $x_i w_i$ are summed up, and the term is subtracted from the sum. The obtained sum expression is described, by means of a non-linear function, as the

output signal y , i.e. as the output vector $\underline{y} = [y_1, y_2, y_3, \dots]$ if y_i represents the load directed for example to one support point $i = 1, 2, 3, \dots$

5 In mathematical terms, the operation of the processing unit can be described in the following form:

$$(1) \quad y = f\left(\sum_{i=0}^{N-1} x_i w_i - \theta\right)$$

10 The term $\sum_{i=0}^{N-1} x_i w_i$ can be replaced by the expression $x^T W$, where $x_N = 1$. Thus the formula (1) is rendered in a simpler form:

$$(2) \quad y = f\left(\sum_{i=0}^N x_i w_i\right)$$

15 The non-linear function f is called the activation function. Generally the non-linearity employed in a perceptron network is a so-called hard limiter non-linearity, which is defined as follows:

$$(3) \quad f_h(s) = \begin{cases} 1, & \text{when } s \geq 0 \\ -1, & \text{when } s < 0 \end{cases}$$

20 The output error caused by the desired output signal of the neural network and the real output value can be minimized for instance by the Widrow-Hoff algorithm, which also is called the LMS (Least Mean Square) algorithm.

25 The output error of the neural network can also be minimized by applying the gradient method, where the penalty function is the sum of the squares of the errors (delta rule). In order to enable the use of the gradient method, the activation function must be continuously derivating. The most generally used continuous activation function is defined as follows:

$$30 \quad (4) \quad f_s(s) = \frac{1}{1 + e^{-(s + \theta_0)\theta_1}}$$

The function 4 is called the Sigmoid function.

The neural network is trained with several test loads and test measurements to process the measurement signals of the said detectors. This is advantageously carried out as follows (cf. Figures 5 and 6). The weights w_{jk}^1 and w_{ij}^2 of the neural network are formatted with small random coefficients, which are normalized within the range [0, 1] i.e.:

- (5) $w_{jk}^1 = \text{rnd}[0, 1]$ weights of the 1st layer
 $w_{ij}^2 = \text{rnd}[0, 1]$ weights of the 2nd layer (etc. through all layers of the neural network)

10

Several test measurements are carried out. At the support points A; A1, A2, A3,... of the structures, there are now arranged predetermined test loads K; K1, K2, K3 with known magnitudes. The measurement signals obtained from the measuring detectors 6 are processed in a corresponding preprocessing unit 7, and they are considered as input signals of the input points of the input level or layer 12 of the neural network, i.e. of the processing units $12^1, 12^2, 12^3, \dots$. The input signal is x_k , and it is thus fed into the input layer ($m=0$; $m = 0, 1, 2, 3, \dots$, where m stands for the processing layer of the neural network in question), so that $V_k^0 = x_k$ with all values k , where k is the index variable of the input layer, $k = 1, 2, 3, \dots$ (i.e. k defines a single input signal from the group of all input signals) and $t = 1 (2, 3, \dots)$ means the time of measurement in question. Thereafter there are calculated the output signals V_i^m for the output layer of the neural network:

15

20

$$(6) \quad V_i^m = f(h_i^m) = f\left(\sum_j w_{ij}^m V_j^{m-1}\right) \text{ for all values of variables } i \text{ and } m$$

25

where f is a predetermined activation function (cf. formula 4), and i is the index variable $i = 1, 2, 3, \dots$ of the output layer (i.e. i defines a single output signal from the group of all output signals).

30 The calculated output signal V_i^m proper and the desired known output signal j are compared, and there is calculated their separation function j , which describes the error or the real loading situation and the loading situation of the moment as calculated by the neural network:

$$35 \quad (7) \quad \delta_i^M = f(h_i^M) \left[\zeta_i^M - V_i^M \right], \text{ where } V_i^M \text{ is the real output signal}$$

The desired output signals y_i are obtained from known test loads directed to the support points, such as from load K of the support point A in Figure 2.

There is further calculated the separation function y_i for the preceding layers of the neural network by resubstituting the errors

$$(8) \quad \delta_i^{m-1} = f'(h_i^{m-1}) \sum_j w_{ji}^m \delta_j^m,$$

where $m = M, M-1, M-2, \dots, 2$, until the separation function y_i is calculated for every processing unit. The weights are updated by calculating the new weight w_{ij}^{new} on the basis of the old weight w_{ij}^{old} and the weight error w_{ij} as follows:

$$(9) \quad w_{ij}^{\text{new}} = w_{ij}^{\text{old}} + \Delta w_{ij}, \quad \text{where}$$

$$(10) \quad \Delta w_{ij}^m = \eta \delta_i^m V_j^{m-1}$$

When the new weights are selected, the new input signals, i.e. measurement signals can be selected by arranging for instance new test loads at the points of measurement. Thereafter the above described procedure is repeated, and new weights are defined again. When the difference of the new and old weights remains below the threshold value, i.e. within the predetermined limits, the weights needed in the measurements proper are defined and they are recorded, whereafter, when the test loads are removed, the neural network is tuned for the measurements proper.

The points of support of the structure 1 are subjected to various static and dynamic loads, depending on the application in question. The neural network is used for observing changes in the load and locating fluctuations therein. Measuring signals are collected from the detectors 6 at suitable predetermined intervals, and the length of these intervals can be adjusted by means of the program when necessary. In the beginning of the measuring step, the filling up of the input layer of the neural network with measurement data is observed, and when the processing units of the input layer have received the measurement data and the input layer is thus filled, the calculation is started. The collecting of measurement data is advantageously interrupted for the duration of the calculation. The calculation is realized as follows (cf. Figure 7).

The measurement signals, i.e. the input signals x_k are fed into the input layer of the neural network, whereafter the output signals of the network are calculated by using the formula

$$5 \quad (11) \quad V_i^m = f(h_i^m) = f\left(\sum_j w_{ij}^m V_j^{m-1}\right) \quad \text{for every } i \text{ and } m$$

Thereafter there is written out the final outcome of the calculation, i.e. the output signals:

$$10 \quad (12) \quad y_i^u = V_i^M \quad \text{for every value } i,$$

which defines a single output signal from the group of all output signals.

Now the next measurement signals can be read into the input layer of the neural network, and the above described calculation procedure can be repeated. Thus the load F directed to one or several support points A is defined on the basis of the measurement signals obtained from the detectors 6 connected to the points of measurement and by utilizing the neural network and the predetermined weights.

20 Figure 8 is a top-view schematic illustration of a vehicle combination, to which the measuring system of the invention is now applied, and of the measuring arrangement in block diagram form. The frames 17, 18 of the tractor 15 and trailer 16 of this combination comprise two parallel frame beams 17a, 17b; 18a, 18b, suitably spaced and interconnected with suitable transversal supports (not illustrated
25 in the drawings). The tractor 15 and the trailer 16 are provided with a number of wheel bogie structures 19; 19¹, 19², 19³, 19⁴, 19⁵, 19⁶, 19⁷, of which in this case four pairs 19; 19¹, 19², 19³, 19⁴ are provided in the tractor and three pairs 19; 19⁵, 19⁶, 19⁷ in the trailer. The wheels 19a, 19b and the wheel bogie structure 19 is in this case attached, by means of leaf springs 20a, 20b, to the two frame beams 17a, 17b; 18a, 18b on both sides of the axis 21, at suitable support and fastening points 22a, 23a; 22b, 23b, as is illustrated in Figures 9 and 10. In the vicinity of the fastening points 22a, 23a; 22b, 23b of the wheel bogie 19, at the points of measurement 24a, 25a, 26a, 27a; 24b, 25b, 26b, 27b, there are arranged measuring detectors 28a, 29a, 30a, 31a, 32a, 33a, 34a, 35a; 28b, 29b, 30b, 31b, 32b, 33b, 34b,
30 35b. The weights of the loads resting on the tractor 15 and the trailer 16 are defined from the measurement signals obtained from the detectors on the basis of the

deformations in the frame 17, 18. By means of the measuring detectors, there are defined the shearing strains directed especially to the frame at the respective points of measurement.

5 The locations of the points of measurement are defined on the basis of the known element method FEM (Finite Element Method). By means of the element method, there are defined the shearing strains directed to the frame beams 17a, 17b; 18a, 18b. The application of the element method to measuring vehicle loads, and particularly to locating points of measurement, is explained in more detail in the international patent application PCT/FI94/00115. Hence the element method can be
10 used for defining the theoretical locations of the points of measurement in relation to the frame. It is pointed out that the detectors can be located at suitable points in the vicinity of the theoretically calculated points of measurement, when the measuring method of the present invention is applied.

15 The points of measurement are located in the vicinity of the support points especially because on the basis of the difference of the shearing strengths affective on different sides of the support points, it is possible to define the support reactions, i.e. weight loads directed to the support points. This is particularly emphasized when there are used continuous loads, in which case the shearing strength curves and their values vary in the lengthwise direction of the load bed, in this case of the
20 frame beams 17a, 17b; 18a, 18b.

The measuring detectors are attached to the calculated points of measurement, as was stated above. Most advantageously the detectors are strain gauge detectors. At each point of measurement, there is attached at least one detector advantageously comprising two or more strain gauge detectors. At each point of measurement, there
25 is thus formed a suitable detector element group, with detector elements on the same level but at an angle with respect to each other. A detector is also attached to the vertical side of the frame beam 17a, 17b; 18a, 18b, at least roughly on the location of the point of measurement. To one and the same point of measurement, there are advantageously attached two detectors on both sides of the frame beam. It is pointed
30 out that the vehicle frame is always subjected to sideways directed strain, when the wheels are located at different heights, or when the vehicle is placed on inclined ground or when the load is arranged asymmetrically. Therefore several detectors are provided at each point of measurement, so that these secondary effects can be eliminated. Moreover, the electric coupling of the detectors can be realized so that
35 the influence of temperature in the obtained measuring results is eliminated.

In the vehicle application of Figures 8 and 9, the strain gauge detectors, particularly the detector groups, are attached so that to the points of measurement 24a, 25a, 26a, 27a; 24b, 25b, 26b, 27b of the frame beams 17a; 18a and 17b; 18b, there respectively belong the detector groups 28a, 29a; 30a, 31a; 32a, 33a and 34a, 35a and 28b, 29b; 30b, 31b; 32b, 33b; 34b, 35b, which are thus located on the opposite sides of the vertical part of the frame beams. The detector groups are connected to the measurement signal preprocessing unit 36, where the signals are suitably processed for the neural network unit 37. The signal preprocessing unit 36 comprises for instance a Wheatstone bridge unit, where to part of the detectors is coupled so that the influences of the deformations in the detectors are amplified in the output poles of the bridge. The difference signal affecting over the bridge is further coupled, via the amplifier provided in the preprocessing unit 36, via a suitable signal processing unit and multiplexer further to the neural network unit 37. In similar fashion, the preprocessing units 36; 36¹, 36², 36³, ... are used for processing the output signals from all detectors provided in connection with the wheel bogies 19, and these signals are fed into the neural network unit 37, as is illustrated in Figure 8. Most advantageously the neural network unit 37 is located in the cabin of the vehicle or the like, where it is connected to suitable display equipment, means for feeding instructions, possible printers and connections to external facilities, such as communication means in order to transport information for instance wirelessly to an external computer or other data collecting unit.

The measurement signals are processed in the neural network unit 37, by means of the neural network program recorded in the memory thereof. This processing is advantageously realized in similar fashion as was illustrated above, in connection with Figures 5 and 6. Figure 11 illustrates in principle the operation of a vehicle measurement system in block diagram form.

The wheel loads of a vehicle combination 15, 16 are calculated by means of the neural network unit 37. First the neural network is trained with test loads and test weighings, by using real wheel weights as feedback (cf. Figures 5 and 6.) The real wheel weights are measured by means of wheel scales 38 located under each wheel 19a (Figures 9, 10 and 11) of each bogie 19. The measurement data is collected from the detectors, from the points of measurement at each bogie 19. Now the employed input signals of the neural network, i.e. the input vector \underline{x} are the measurement signals obtained from the detectors, from around each point of support 22a, 23a; 22b, 23b, which signals are preprocessed in the respective preprocessing units 36 and then averaged. By means of the neural network, the infed measurement

data is processed according to the weight accumulations, so that the obtained output signal is the vector $y = [y_1, y_2, \dots, y_w]^T$, where y_i is the value of the load strain directed to one wheel. The internal operation of the neural network is described above, in connection with Figures 2 - 7 and formulas 1 - 10. This embodiment also
5 introduces a three-layered neural network, including an input layer, a hidden layer and an output layer, as is illustrated in Figure 11. In addition to this, Figure 11 shows the reference layer, whereto the weight values obtained from the wheel scales 38 are thus fed, and with which the signals obtained from the detectors and processed by the neural network are compared, and whereby the suitable weights
10 are finally calculated for the signals in between the layers of the neural network (cf. Figure 6).

There can be several measurement and calculation cycles, and in between them it is possible to adjust the load of the tractor and the trailer in a desired fashion and to
15 repeat the calculations in order to check the weights of the neural network. Thereafter, when the neural network is trained by means of test loads and the weights are thus determined, it is ready to be used in real time for observing the loads in the tractor and the trailer, according to the procedure explained above (cf. Figure 7 and formulas 10 and 11).

20 In the above specification, the invention is explained with reference to a few preferred embodiments only. It is, however, pointed out that the invention can be modified in many ways within the scope of the inventional idea restricted by the appended patent claims.

Symbols:

x_i Input

w_{ij}^m Weight (from neuron i , to neuron j , layer m)

θ^m Bias-term (layer m)

V_i^m Output (node i , layer m)

h_i^m Neuron sum (node i , layer m)

ζ_i^μ Train data (output node i , pattern μ)

δ_i^m Difference (node i , layer m)

Patent claims

1. A method for measuring loads (F) directed to structures (1), wherein the detectors (6), advantageously strain gauge detectors, measuring the deformation of the structures are attached to the frame parts (2; 3) of the said structures, most advantageously in the vicinity of the support points (A), **characterized** in that the measurement signals obtained from the measuring detectors are processed by means of a predetermined neural network, so that from the output layer of the neural network, there are obtained the loads (\underline{y}) directed to desired points of the structures, and that the neural network is in advance trained with test loads to process the measurement signals from the said detectors (6).

2. A method according to claim 1, **characterized** in that

- at the support points (A; A1, A2, A3,...) of the structures (1), there are arranged predetermined loads (K; K1, K2, K3,...) of known magnitudes;
- the measurement signal s obtained from the measuring detectors (6) are preprocessed and considered as input signals (x ; $x_0, x_1, x_2, x_3, \dots$) from the input units ($12^1, 12^2, 12^3, \dots$) of the input layer (12) of a predetermined neural network (cf. Figure 3);
- all measurement signals are processed in the neural network by using preliminary weights (w_{jk}^1, w_{ij}^2) in between units of the different layers (12, 13; 13, 14) of the neural network, so that the computational load values directed to the said support points (A) of the structures are defined as the output signals (y ; y_1, y_2, y_3, \dots) of the output units of the output layer (14);
- the values of known loads directed to the support points (A) of the structures are compared with the computational load values, and on the basis of the difference of these values, there are defined new weights which replace the preliminary weights (formulas 6, 7, 8, 9 and 10);
- all measurement signals are reprocessed in the neural network by using the new weights in between the different units of the layers of the neural network, so that the computational load values directed to the said support points of the structures are defined as output signals of the output units of the output layer of the neural network;
- the values of known loads directed to the support points of the structures are compared with the new computational load values, and if the difference surpasses the preset limits, on the basis of the differences of these values there are again defined new weights, and the above described calculation procedure is repeated, and if the difference now remains within the allowed limits, the weights are retained;

- the predetermined loads (K) arranged at the support points of the structures are removed; and
- on the basis of the measurement signals obtained from the detectors (6) connected to the support points (A), the load (F) directed to one or several support points (A) is defined by utilizing the neural network and the predetermined weights (formulas 11 and 12).

3. A method for measuring the weight and/or weight distribution of a vehicle, in which method the detectors (28a, 29a, 30a, 31a; 32a, 33a, 34a, 35a; 28b, 29b, 30b, 31b; 32b, 33b, 34b, 35b), advantageously strain gauge detectors, measuring the deformations of the structures are attached to the bearing structures of the vehicle, particularly to the frame parts (17a, 17b; 18a, 18b), most advantageously in the vicinity of the support points (22a, 23a; 22b, 23b), **characterized** in that the measurement signals ($x; x_0, x_1, x_2, x_3, \dots$) obtained from the measuring detectors are processed by means of a predetermined neural network (cf. Figures 8, 9, 10 and 11), so that they are fed to the neural network through the input layer thereof, and from the output layer of the neural network, there are obtained the weight loads directed to the desired points of the vehicle, particularly to one or several support points (such as 22a, 23a; 22b, 23b), and that the neural network is in advance trained with test loads to process the measurement signals of the said detectors.

4. A method according to claim 3, **characterized** in that

- on each wheel (19a) and/or wheel bogie (19) of a vehicle (15, 11) there is set a predetermined load, which is measured;
- the measurement signal obtained from each detector (28a, 29a, 30a, 31a; 32a, 33a, 34a, 35a; 28b, 29b, 30b, 31b; 32b, 33b, 34b, 35b) is fed into the neural network unit (37), where the measurement signal of each detector or detector group is considered as the input signal ($x; x_0, x_1, x_2, x_3, \dots$) of the input unit of the input layer of the neural network, and the said signals are processed in the neural network so that the weights of the network are defined by means of the measured wheel weights and total weight; whereafter
- the weight distributions, bogie weights, wheel weights and/or total weight can be defined in real time by utilizing the measuring signals and the said neural network.

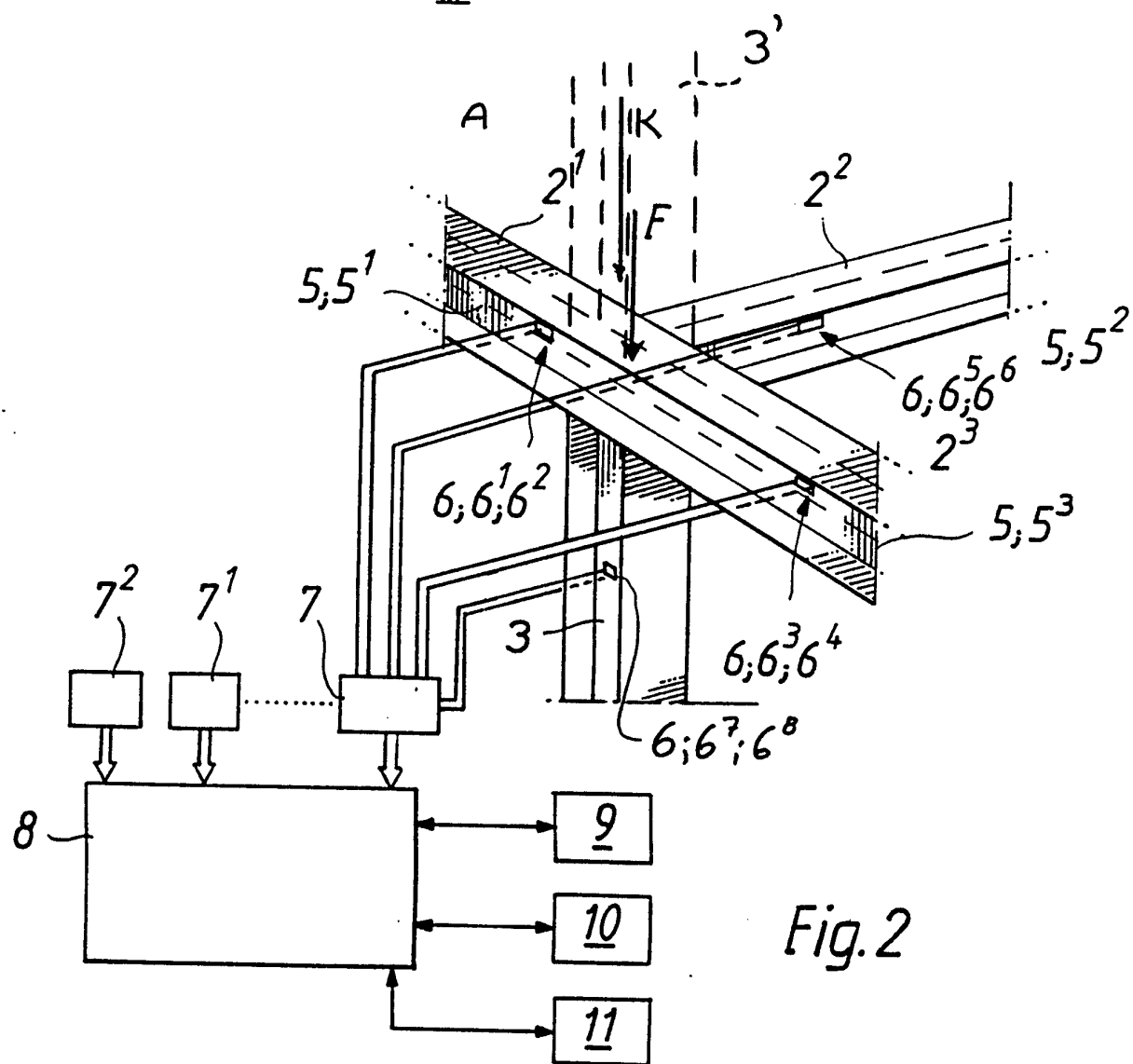
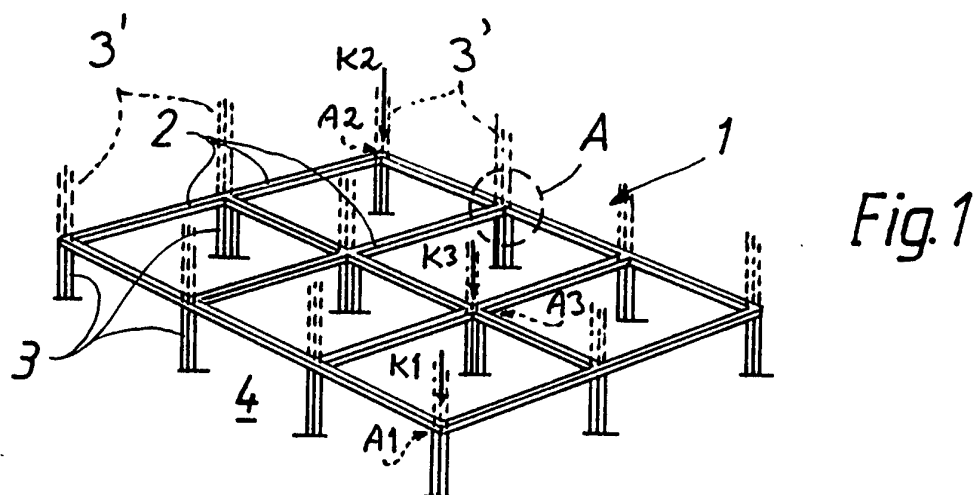
5. A method according to claim 3 or 4, **characterized** in that the employed neural network is a multilayered network (cf. Figures 3 and 11), such as a three-layered perceptron network, comprising an input layer, at least one hidden layer and an output layer, in which network the measurement signals fed into the input units

of the input layer are multiplied by the first weights, and the products are summed up according to a predetermined procedure in the units of the hidden layer, whereafter there is calculated the value of a suitable function, such as the Sigmoid function, with the said sum, and the signals obtained from the units of the hidden
5 layer are multiplied by other weights, and the obtained products are suitably summed up in the output layer in order to create the output signal of the desired output unit.

6. A method according to claim 5, **characterized** in that the signal obtained from
10 each point of measurement, from one or several detectors, is preprocessed, such as amplified and stabilized, and it is interpreted as the input signal of one unit of the input layer of the neural network.

7. A method according to claim 5 or 6, **characterized** in that the filling of the
15 input layer with measuring data is observed, and when the input layer is filled, the calculation is started.

8. A method according to any of the preceding claims 3 - 7, **characterized** in
20 that the measurement signals are selected in the vicinity of the support points of the wheels of the vehicle, and that strain gauge detectors are installed in the frame structure of the vehicle on the said spots.



2/8

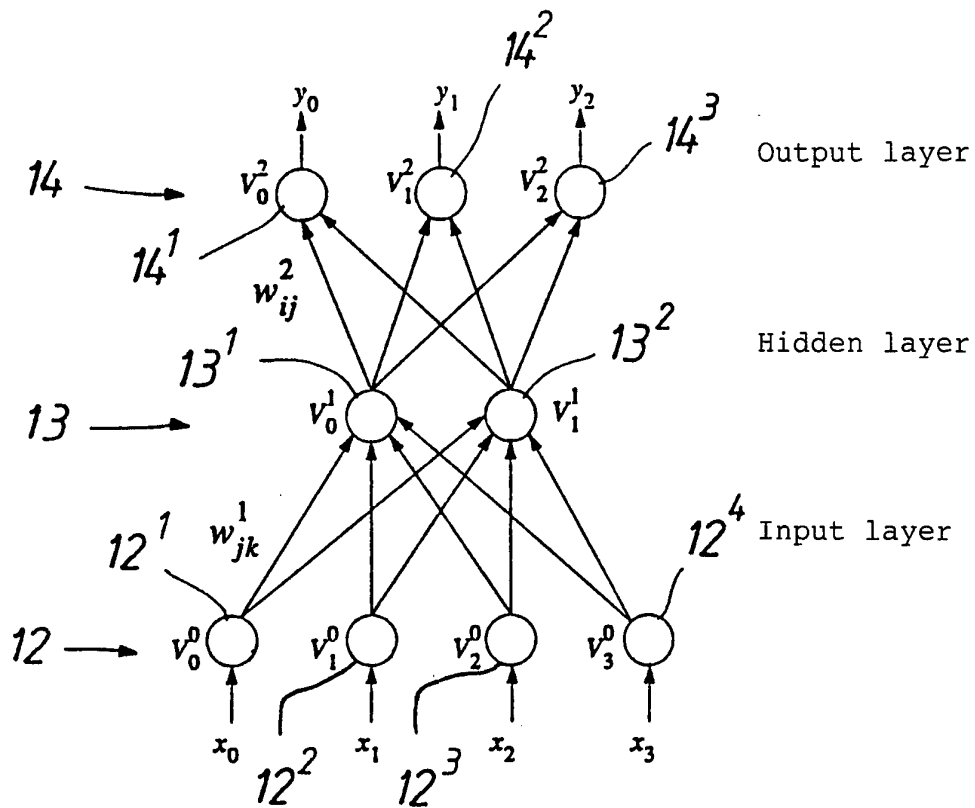


Fig. 3

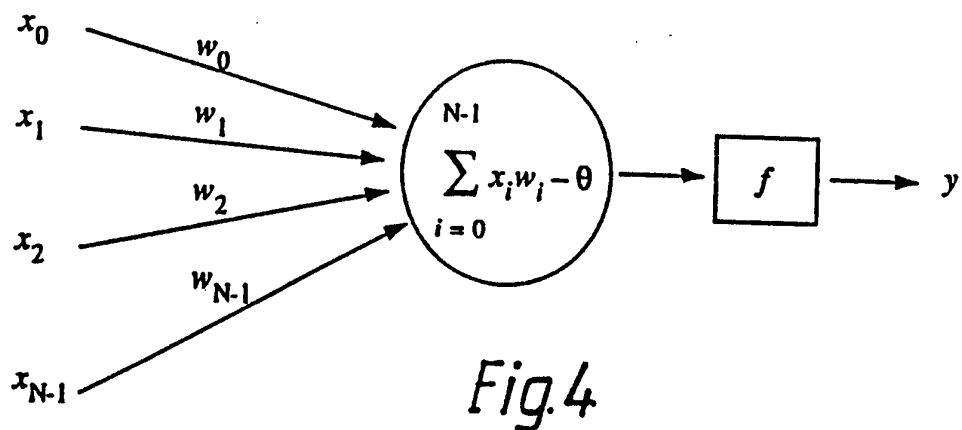


Fig. 4

FIG. 5

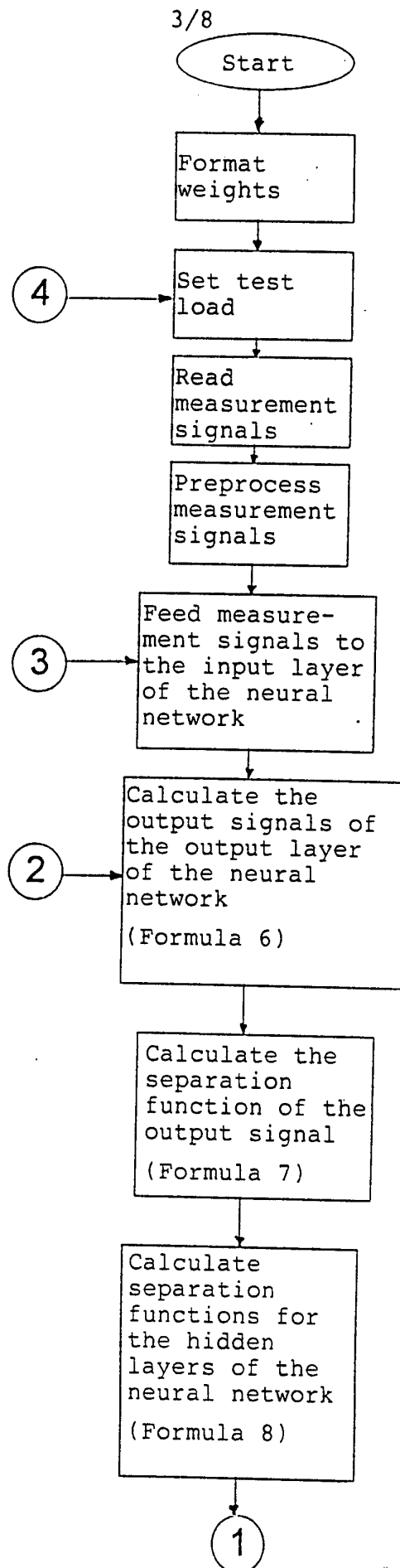
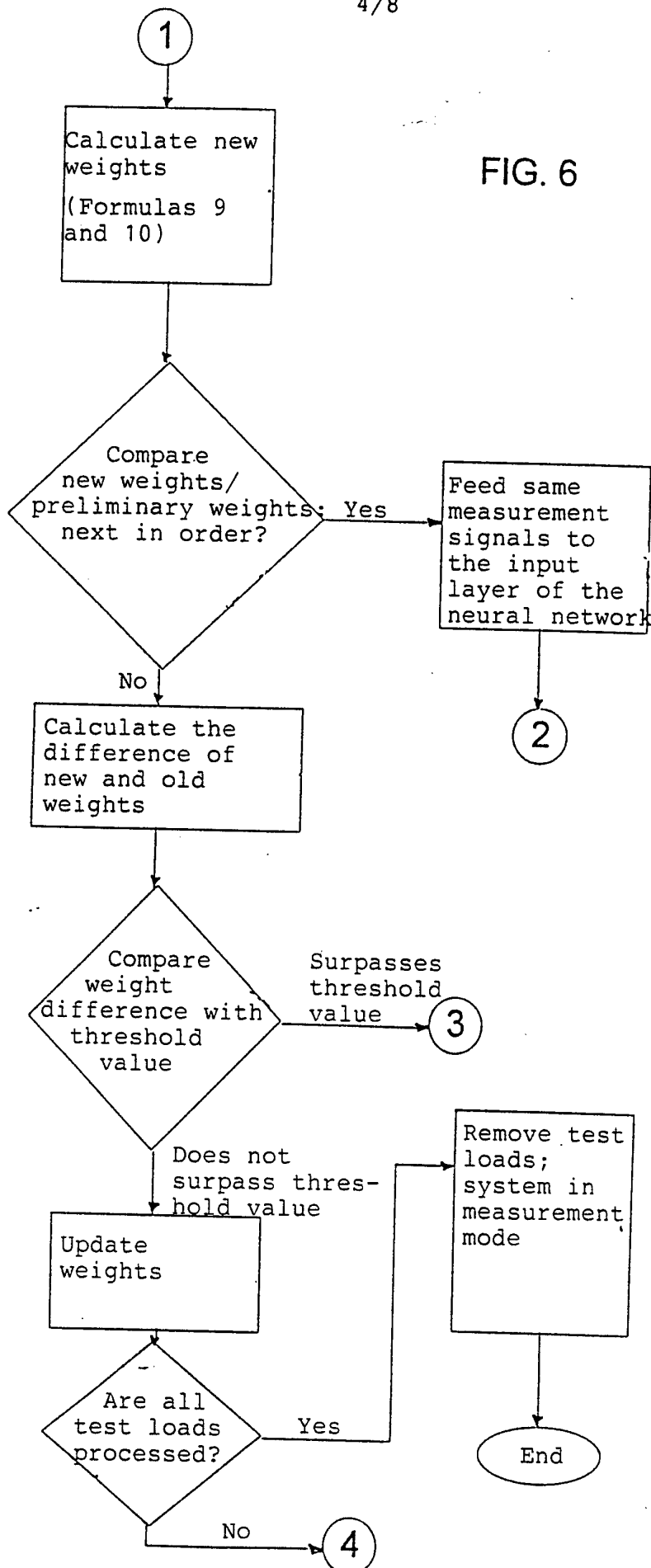
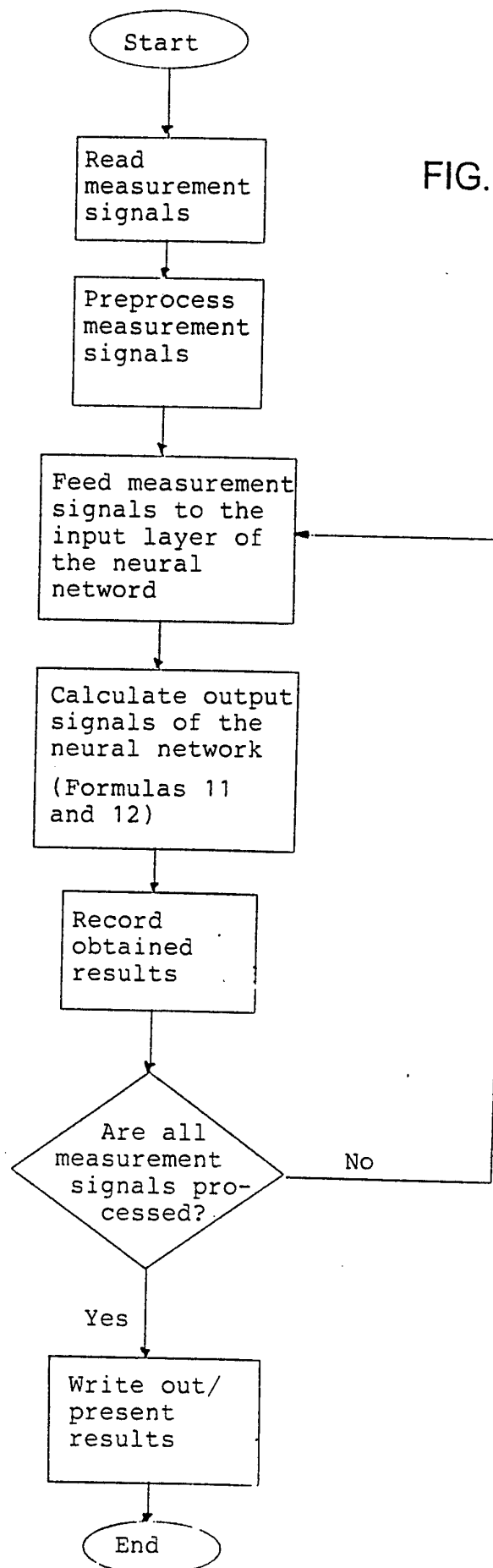


FIG. 6



5/8

FIG. 7



6/8

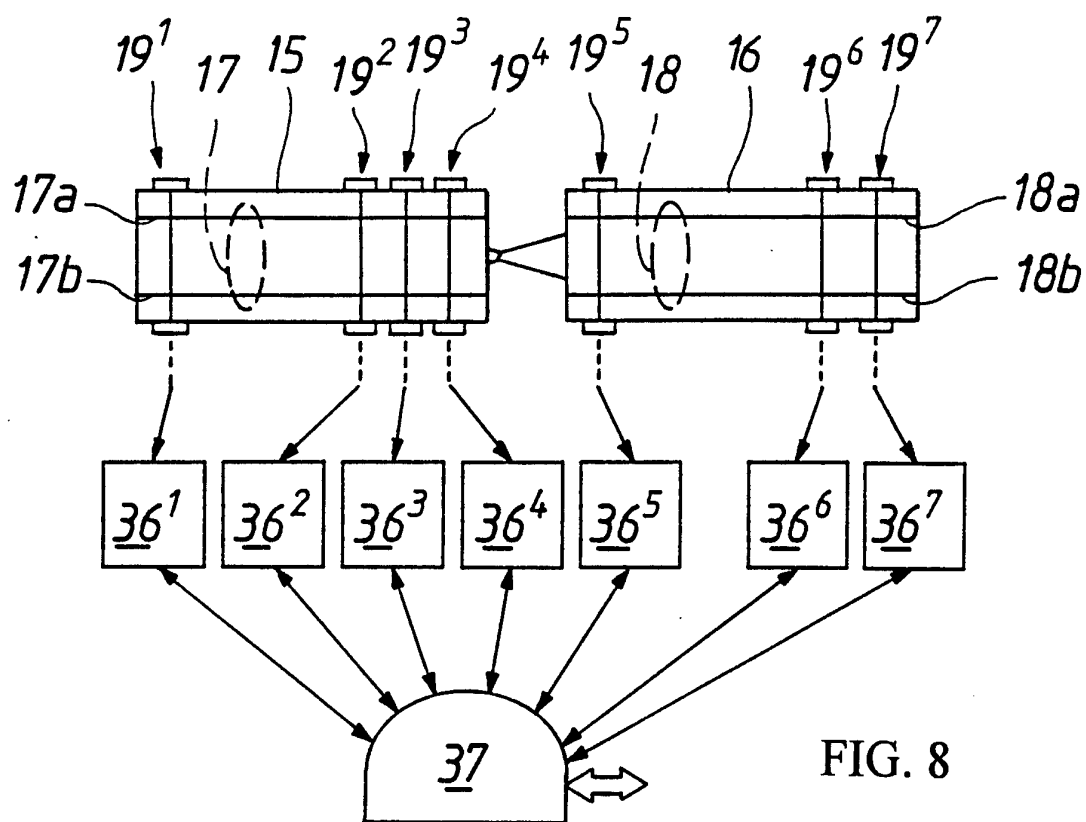


FIG. 8

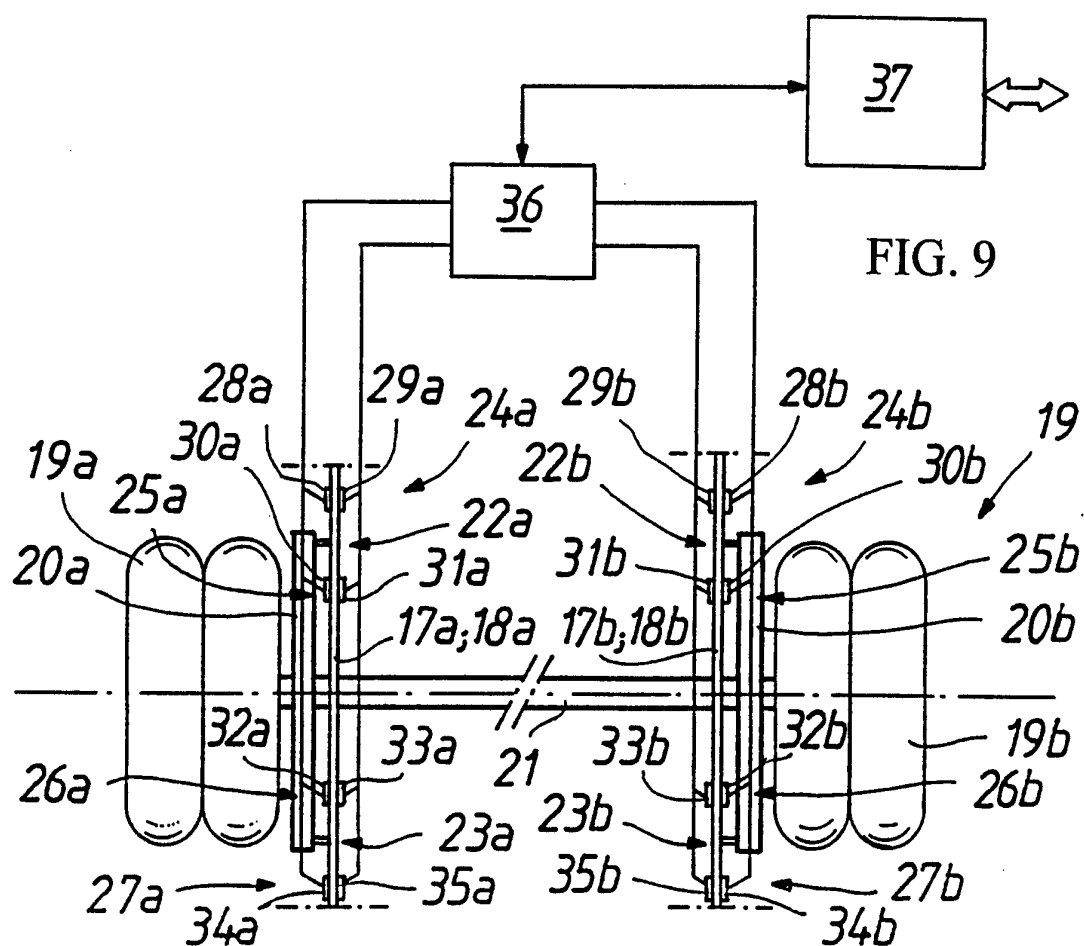


FIG. 9

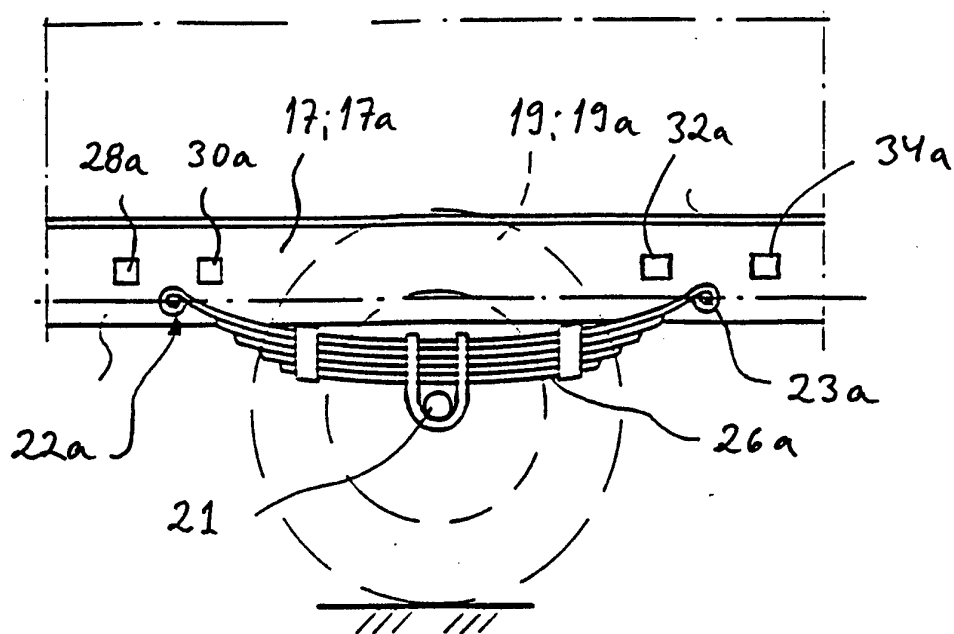


FIG. 10

8/8

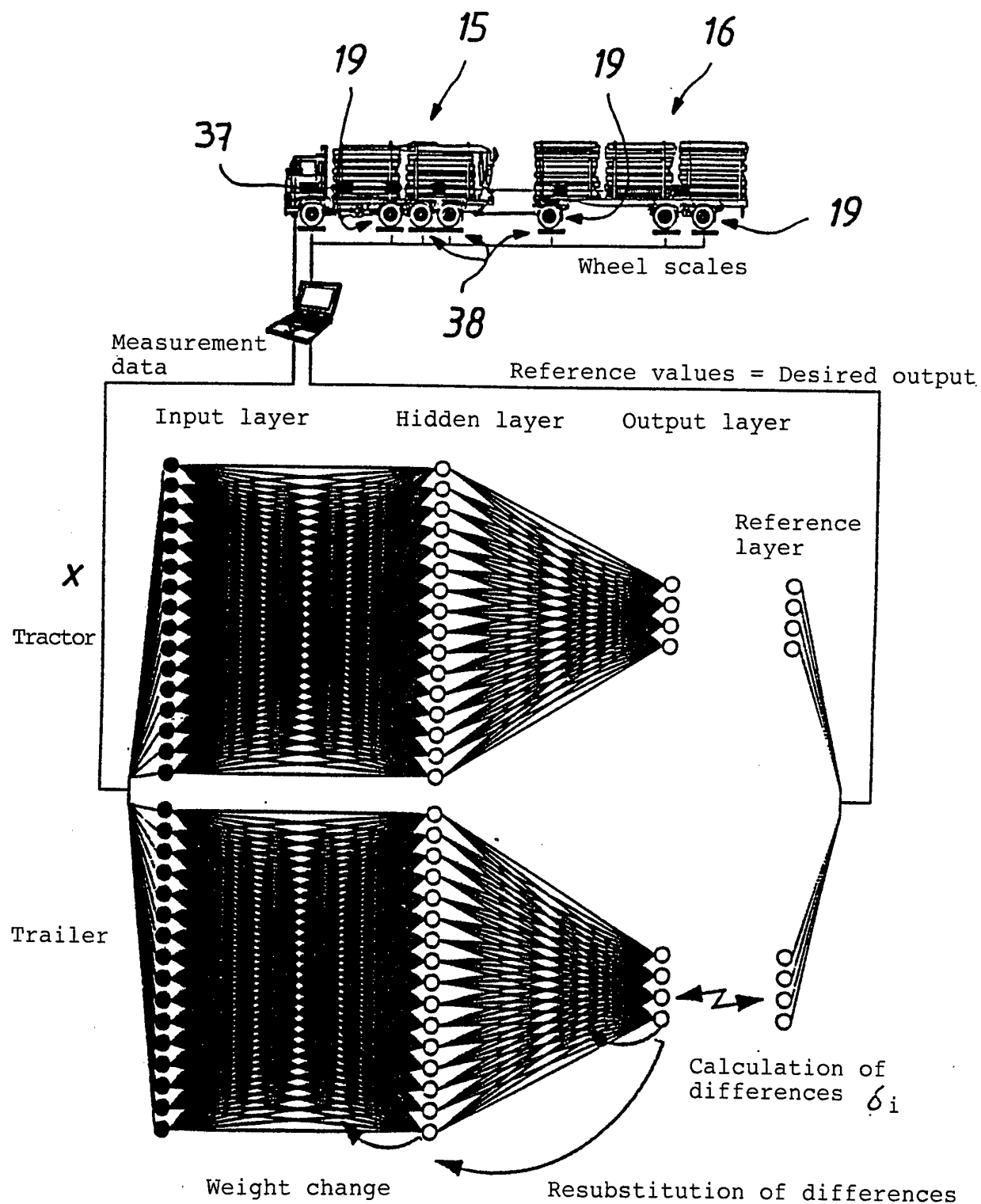


FIG. 11

INTERNATIONAL SEARCH REPORT

International application No.

PCT/FI 95/00133

A. CLASSIFICATION OF SUBJECT MATTER

IPC6: G01G 19/12, G06F 15/18

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC6: G01G, G01L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

DIALOG

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP, A2, 0545641 (EXXON RESEARCH AND ENGINEERING COMPANY), 9 June 1993 (09.06.93), page 15, line 11 - page 18, line 30, figures 1-12 --	1
A	US, A, 4979124 (WOLFGANG H. SACHSE ET AL), 18 December 1990 (18.12.90), column 7, line 45 - column 10, line 40, figure 1 --	1,3
A	US, A, 5285523 (HIROSHI TAKAHASHI), 8 February 1994 (08.02.94), figure 1, abstract --	1,3

☒ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

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"&" document member of the same patent family

Date of the actual completion of the international search

14 June 1995

Date of mailing of the international search report

22 -06- 1995

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INTERNATIONAL SEARCH REPORT

International application No.

PCT/FI 95/00133

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO, A1, 9119172 (KOIVISTO, VESA), 12 December 1991 (12.12.91), figures 1-6, abstract --	1,3
P	WO, A1, 9423275 (KOIVISTO, VESA), 13 October 1994 (13.10.94), figures 1-5, abstract -- -----	1,3

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/FI 95/00133

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP-A2- 0545641	09/06/93	CA-A- 2083737 FI-A- 925454 JP-A- 5248980 US-A- 5396817	30/05/93 30/05/93 28/09/93 14/03/95
US-A- 4979124	18/12/90	NONE	
US-A- 5285523	08/02/94	JP-A- 4131561	06/05/92
WO-A1- 9119172	12/12/91	EP-A- 0573420 US-A- 5366033	15/12/93 22/11/94
WO-A1- 9423275	13/10/94	NONE	