# PATENT SPECIFICATION

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## (54) AN ARRANGEMENT FOR ACTIVE COMPENSATION OF UNWANTED RELATIVE MOVEMENTS, PREFERABLY DURING DISPOSITION OF LOAD (CARGO)

(71) We, A/S STRØMMEN STAAL, a Norwegian Body Corporate, of N-2010 Strømmen, Norway, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:

The present invention relates to an arrangement for active compensation of unwanted relative movements, preferably during disposition of load (cargo), using a long-periodic acting system for compensation of a static loading caused by said load and a short-periodic acting system for active compensation of unwanted relative movements of the load relative to a reference level.

During disposition of load by means of a floating crane to a stationary installation there may during wave motion easily arise large relative movements of load relative to said installation.

Said relative movements may also easily yield overloading of the construction which performs the dispositioning of the load.

Upon disposition of a large load, e.g. of several hundred tons, the forces which are released upon impact created by such movements may cause large damage both to the load itself and to the installation. In order to decrease the risk of such impact one is presently and substantially restricted to dispositioning of the load when the conditions for minimum relative movements are present, i.e. during low wave motion. Thus, such operations are likely to be postponed until the wave motion conditions are satisfactory.

From the prior art, systems for solving problems relating to unwanted movements are known. In U.S. Patent No. 3,314,657 there is described a system having the purpose of maintaining a predetermined tension in a cable by means of hydro pneumatic means. This is an example of a passive system. A piston cylinder is positioned between two pulleys and by variation of the movements of the piston relative to the cylinder the cable tensioning is altered as required. The patent however, does not teach how the task may be solved when having extremely large loads as well as transients as a result of relative movements. From the Norwegian applications No. 74.3601 (equivalent to British Patent Application No. 47125/73, (Patent No. 1,397,880) Brown Brothers & Company Ltd.) a wave motion compensating system is known for maintaining a load which is suspended on a floating platform at substantially constant level and comprising a passive load carrying system having a resilient load carrying coupling which can be mounted between a fixed support on the platform and a load which is to be carried. The installation is based on a closed system, where increase in liquid pressure in a wave motion compensating cylinder causes transfer of liquid from said cylinder to a shock absorbing cylinder and upon the operation of the latter an increase in pressure in an associated closed pneumatic system. The installation thus attempts to achieve a load balance by means of a slightly increased liquid pressure. From the Norwegian Patent Application No. 74.3620 (equivalent to U.S. Patent Application No. 404.617, Global Marine, Inc.) a wave motion compensator is known which intends to maintain the loading or the position constant for an object which is suspended from a floating vessel when the vessel moves up and down on the water surface. The compensator comprises a hydraulic servo system which can offer active assistance to a passive pneumatic system, such that said loading or position is kept within predetermined narrow limits even when the movements of the vessel are quite large. The compensator, however, requires that the pressure which is present in the compensator cylinder is sufficient both to hold the load, in the example shown a drilling wire, and compensate for the present movements due to wave motion. This results in that the "passive" compensating pressure necessarily becomes particularly high even though the "active" compensating pressure variations are small.

According to the invention there is provided an arrangement for active compensation of unwanted relative movements during disposition of a load using a long-periodic acting system for compensation of the static loading caused by the load and a short-periodic acting system for active compensation of unwanted relative movements of the load relative to a reference level, the long-periodic system including a compensating cylinder provided with two pistons acting in opposite directions, the compensating cylinder being connectable through connector means to one or more pressure loaded reservoirs, the long-periodic system being pneumatic using air or inert gas as operational medium, and hydraulic cylinders being used in the short-periodic system, the position of which is determined by measurement of the acceleration of the load, the hydraulic cylinders being mechanically linked to the pistons of the compensating cylinder.

The present invention will be further described, by way of example, with reference to the accompanying drawings, in which

Figure 1 illustrates dispositioning of load to a stationary installation by means of a floating crane;

Figure 2 illustrates the system in Figure 1 in enlarged scale;

Figure 3 shows an arrangement not according to the invention but shown for the purpose of explanation;

Figure 4 shows another arrangement not according to the invention but shown for the purpose of explanation;

Figure 5 *a* and *b* are diagrams illustrating operation of the arrangement shown in Figure 4;

Figure 6 illustrates dispositioning of load on a moveable e.g. floating, support by means of a floating crane.

Figure 7 shows a preferred embodiment of the invention;

Figure 8 shows another preferred embodiment of the invention;

Figure 9 shows a flow diagram illustrating operation of the embodiment of Figure 8; and

Figure 10 shows part of a preferred embodiment including a safety device.

In Fig. 1 there is shown a stationary installation 1, e.g. a platform mounted on an oil drilling field, which platform has a deck 2 on which a load 3 is to be placed. The load 3 is here considered to have a substantial weight, e.g. 50—100 tons. The load may be moved by means of a floating crane 4 consisting of the crane beam 5, the operation wire or wires 6, pilot cabin 7, a deck 8 and buoyancy elements 9 and 9′. Upon wave movement the floating crane will be given an angular velocity $\omega$. Upon such movement the load will move a small distance up and down as indicated by $+\Delta h$ and $-\Delta h$. The rectilinear movement of the load 3 will have a velocity $v$.

With reference to Fig. 2, with an angular velocity $\omega$ as a result of e.g. wave motion, the loading beam 5 will have a movement as shown in the figure. The outer end of the beam moves over corresponding distances $+\Delta h_1$ and $-\Delta h_1$. This movement must be compensated and this can be carried out by means of a pulley system where the number of parts in the system are equal to $t$ and where the change $\Delta h_1$ is equal to $t \times \Delta l$, where $\Delta l$ is the length of each portion being altered. The system 10 consists of pulley blocks 11 and 12 as well as pressure means 13 positioned between the said blocks. At the outer end of the crane beam 5 an accelero-meter 14 is attached, said accelero-meter sensing vertical movements of the outer end of the beam and therefore also the vertical movement of the load 3. Despite the movement of the beam 5 being greatly compensated by means of the system 10, there will still be present some vertical movements $\Delta h_2$ at the load 3, which vertical movements must be made as small as possible.

For compensating the said unwanted movements relative to the deck 2 there is shown in Figure 3 (for purposes of explanation only and not according to the invention) a pressure cylinder 13 consisting of a piston 14, a cylinder 15 and a piston rod 16. At the outer ends 17 and 18 the said pulleys 11 and 12, respectively, are mounted. The movement of the piston 14 will in the embodiment shown be a total of $2 \times \Delta l$. A liquid pressure $P_1$ acting against the piston 14 is supplied from a pressure source 19 consisting of a pressure cylinder having an air volume or inert gas volume $V_2$ at pressure $P_2$ and a nominal liquid volume $V_1$. In a preferred embodiment $V_2 \approx 10 \times V_1$.

In order to keep the energy consumption of the compensator as low as possible $P_2$ should be equal to $P_1$. If $P_2 < P_1$ air or gas is supplied by means of the pump 20 to volume $V_2$. If $P_2 > P_1$ air or gas is released from the volume $V_2$. In order to ensure a quick compensation for even small changes there has been arranged a heavy duty liquid pump 21 which can feed liquid in one or the other direction as indicated in the figure by arrows. The pump is driven by a motor 22.

II indicates the long-periodic system of Fig. 3, where the period preferably is greater than 25 seconds. A logic unit 23 is connected to the pressure sensors 24 (for measuring the pressure $P_1$) and 25 (for measuring the pressure $P_2$) and the outputs of the logic unit are connected to the valve 26 and the pump 20. A further input to the logic unit 23 is the nominal value $L_0$ which has to be fed through the wire 27 to the unit 23, $L_0$ designating the deviation from the nominal position of the piston 14. The logic unit 23 will preferably have a time delay of approximately 5 seconds in order to ensure that only the long-periodic movements are compensated.

The motor 22 driving the pump 21 is controlled by a logic unit 28 the input signals of which comprises signals representative of the instantaneous position of the piston 14, and said signal is fed through the wire 29. Further through the cable 30 there is fed known parameters as e.g. elasticity of the load cable and the crane structure, and further signals from the accelero-meter 14 are fed through the line 31.

As illustrated, by way of explanation and not according to the invention, information may be fed through the line 32 from the load yoke from which the load is suspended and if the support, upon which the load is to be placed, is moveable information may be given through the line 33 about the pattern of movements of said support relative to the floating crane. The portion of the system thus labelled I is the short-periodic part having a typical period of approximately 5 seconds. The portion thus takes care of the dynamic variations in movement.

Although the system of Fig. 3 is technically realizable there will be some problems attached to the pump 21. Relative to atmospheric pressure the said pump will have to be exposed to such a heavy pressure that problems will exist with regard to keeping the pump tight.

In Fig. 4 (by way of explanation and not according to the invention) the right hand portion is the long-periodic system and is in principle a balancing system. The left hand portion takes care of the active compensation of the unwanted relative movements. Thus, as seen, the pressure means 13 of Figure 3 is here replaced by two pairs of cylinders 34 and 35 with pistons 36 and 37 and piston rod 38 and 39, respectively. The piston rods 38 and 39 are connected to a common link 40. The cylinder 35 has a supply of air or inert gas from a pressure cylinder 41 having an extra pressure cylinder 42 connected through a valve 43. The pump 44 maintains the pressure in the cylinder 41 at the ever required pressure. This is carried out as described in connection with the pump 20 of Fig. 3, and when supply from the unit 41 to unit 42 is to be made, the valves 45′ and 45″ are opened, whereas when supply of air or gas is to be made from the supply 42 to the supply 41 the valves 46′ and 46″ are opened. The relative movements of the short-periodic system are handled by the pump 47 which in this case may be connected to a conventional reservoir or a liquid pressure source having a nominal pressure which is substantially less than the pressure acting on the pump 21 in Fig. 3.

In Fig. 5a there is shown how a system not according to the invention upon loading goes from the neutral position $L_0$ to the lower stopper and as a result of the increases in the balancing pressure gradually is brought back to the neutral position $L_0$.

The corresponding diagram is shown (by way of example and not according to the invention) in Fig. 5b, where in the cylinder 35 there is present a load yoke pressure, and upon loading there is an increase of said pressure until the balancing pressure or the load carrying pressure at the neutral position $L_0$ is reached. The hydraulic cylinder 34 will take care of the variations in the pressure $\Delta P$ which take place due to unwanted relative movement.

In Fig. 6 there is shown an embodiment where the load is to be placed upon a moveable support, e.g. floating platform. The floating crane will here have the same angular velocities as previously discussed and the only new parameter which must be registered is the instantaneous movement of the platform deck 53 relative to the load 3 which is in motion. This can be made by an accelerometer 54 mounted on the platform deck 53 with the transfer of data from the accelerometer 54 to a logic unit being by wireless communication.

In Fig. 7 is shown an arrangement constituting a preferred embodiment of the invention. The short-periodic system includes two hydraulic cylinders 55, 55′, the one end of which is fixedly mounted to the crane or some other fixed support. The piston rods 55″ and 5‴ of the two cylinders are respectively connected to the piston 56′ and 56″ of a pneumatic double-piston cylinder 56 which is included in the long-periodic system. The cylinder 55 compensates for a displacement $L_1$ measured by the position gauge 81, and the cylinder 55′ compensates for a displacement $L_2$ measured by the position gauge 82. At a position of equilibrium the distances *a*, *b*, *c*, *d* are preferably the same.

For compensation of variations in loading by means of the long-periodic system the pneumatic cylinder 56 is in communication with a pressure tank 57 through a valve 60. In a preferred embodiment where three reservoirs having the same volume are used, the pressure tank 57 has a nominal pressure large enough to carry the load and a volume which is large relative to the cylinder volume. The tank 57 constitutes the working reservoir for the cylinder 56. The working cylinder 56 is also connected to a low pressure reservoir 58, the nominal pressure of which is low. The connection from said tank 58 to the cylinder 56 is made either through the valve 61 or through a choke valve and heat exchanger 74 and a valve 80 in communcation with said working reservoir 57.

A high pressure reservoir 59 is connected to the working reservoir through a valve 79 and a choke valve and a heat exchanger 75. The container 59 has preferably a high nominal pressure.

The container 58 is connected to a pressure gauge 68. The container or tank 57 is connected to a pressure gauge 69. The tank 59 is connected to a pressure gauge 70.

The compressor 71 is provided with a suction pipe 72 and a pressure pipe 73. In order to maintain nominal pressure in the tanks 58, 57 and 59 a selective control of the valves 64, 65; 62, 63; 66, 67, can be made.

Measurement data from the pressure gauges 68, 69 and 70 as well from the position gauges 81 and 82 are fed into an input block 76 which through a logic device 77 including an analog-to-digital converter and an output block 78 causes respectively opening or closing of one or more of the valves 64, 62, 66, 65, 63, 67, 80, 79, 60, 61 as well as start or stop of the compressor 71.

Fig. 8 is a modification of the device in Fig. 7. The compensation cylinder 56 is supplied with a pressure medium through a feeding pipe 83 which communicates with the valves 61, 60 and 84. The valves 61, 60 and 84 are respectively communicating with the pressure tanks 58, 57 and 59. The heat exchanger 74 between the tanks 58 and 57 is quite necessary in order to compensate for heat generation or cooling effect upon large pressure transients. The heat exchanger 75 has a corresponding functioning.

The volumes of the containers 58, 57 and 59 are preferably the same, so that the reservoirs denoted by $R_A$, $R_B$ and $R_C$, in Fig. 8 may be identical.

The relationships between the nominal pressure are in the example chosen 1:3:6.

In order to change the pressure in the tank 58 or 59 the valve 85 may be opened. This will correspond to opening of the valves 64 and 66 in Figure 7.

Between the tanks 58 and 59 there has been arranged a compressor which is suitable to operate from a high pressure to an even higher pressure. The compressor is indicated by the operational arrow 86. A corresponding compressor is found between the tanks 58 and 57, labelled by the operational arrow 87 and between the tanks 57 and 59, labelled by the operational arrow 88.

In the example chosen the valve 61 is suitable for e.g. a load between 0 and 60 ton, the valve 60 for a load between 60 and 130 tons and the valve 84 for a load between 130 and 200 tons. These are only chosen examples and are not necessarily restrictive to the working range.

By using compressors operating between a high pressure and an even higher pressure it is obtained that one may use modern and cheap compressors having a moderate power consumption relative to compressors which have to operate between atmospheric pressure and operational pressure.

The system of Fig. 8 makes use of three tanks or reservoirs which form part of a closed system and one may therefore make use of inert gas for operational purposes.

The system of Fig. 8 makes possible that the loading time will be the least possible. The loading time is a substantial factor when the same hoisting device is to operate with minimum and maximum loading subsequently. In extreme cases it may take up to 24 hours to establish the sufficient working pressure. This problem is alleviated to a substantial extent by the present system.

By using a double-acting compensation cylinder 56 the piston velocity is only one half relative to that of a single cylinder since piston velocity greater than 1 meter pr. second should be avoided. This is a substantial advantage since thereby it is possible to compensate for twice as high velocities at the crane beam tip.

In Fig. 9 is as an example shown a flow diagram for use in connection with the system as shown in Fig. 8.

In Fig. 10 is shown a safety device to be used in connection with the compensation cylinder 56. At the unpressurized sides of the pistons 56′ and 56″ there has been introduced hydraulic oil 89 and 89′ from a low pressure reservoir 90. In the supply pipes to the oil volumes 89 and 89′ there is included a choke valve 91 which operates upon large flow-through velocities. One has now a pneumatic cylinder with a liquid piston.

At the pressurized sides of the pistons there is supplied, in a modified embodiment of Fig. 8, liquid through a gas pressure/liquid pressure converter 92. The converter 92 thus serves as a high pressure reservoir for the cylinder 56. The volume of the reservoir 92 must at least be equal to the total volume of the cylinder 56. The liquid is carried through the pipe 83' and a choke valve 93 to the working cylinder, as will appear from Fig. 10. The gas pressure pipe 83 leads to the valves 61, 60 and 84 as shown in Fig. 9.

The object of the device in Fig. 10 is to prevent the pistons in the cylinder 56, e.g. upon wire fracture when there is thus no longer any counter-force against the pressure action of the pistons, from being caused to more or less be shot out from the cylinder 56. The hydraulic oil 89 89' as well as the choke valve 91 will act as an effective shock damper and substantially reduce mechanical damage and possible injuries to human beings. The valve 93 serves the same function since it will be blockaded upon too large a flow through the supply pipe 83.

WHAT WE CLAIM IS:—

1. An arrangement for active compensation of unwanted relative movements during disposition of a load using a long-periodic acting system for compensation of the static loading caused by the load and a short-periodic acting system for active compensation of unwanted relative movements of the load relative to a reference level, the long-periodic system including a compensating cylinder provided with two pistons acting in opposite directions, the compensating cylinder being connectable through connector means to one or more pressure loaded reservoirs, the long-periodic system being pneumatic using air or inert gas as operational medium, and hydraulic cylinders being used in the short-periodic system, the position of which is determined by measurement of the acceleration of the load, the hydraulic cylinders being mechanically linked to the pistons of the compensating cylinder.

2. An arrangement as claimed in claim 1, in which a heat exchanger is arranged between at least two of said reservoirs.

3. An arrangement as claimed in claim 1, in which a compressor is arranged between at least two of said reservoirs, said compressor compressing from a high pressure to a more elevated pressure.

4. An arrangement as claimed in claim 1, in which the non-pressurized sides of the pistons in said cylinder are supplied with liquid at low pressure, the amount of the liquid at high flow rates through a choke valve communicating with a reservoir causing closure of the valve.

5. An arrangement as claimed in claim 1, in which a pneumatic/hydraulic converter is included in the long-periodic system between the connector means and the compensating cylinder.

6. An arrangement as claimed in claim 1, in which the short periodic system includes means for detection of relative movements of the load relative to a reference level, said means including accelerometers each attached to the outer end of a loading beam, to the load or to a yoke to which the load is attached, respectively, and also to said reference level when the same is movable, and a logic device for comparing measurements from said accelerometers.

7. An arrangement as claimed in claim 6, in which the logic device includes an analog-to-digital converter.

8. An arrangement as claimed in claim 6, in which the transfer of measurement results from the accelero-meter arranged at the reference level is made by wireless communication.

9. An arrangement for active compensation of unwanted relative movements during disposition of load, substantially as hereinbefore described with reference to and as illustrated in Figures 1, 2 and 6 to 10 of the accompanying drawings.

10. A crane including an arrangement as claimed in any one of the preceding claims.

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*Fig. 1.*

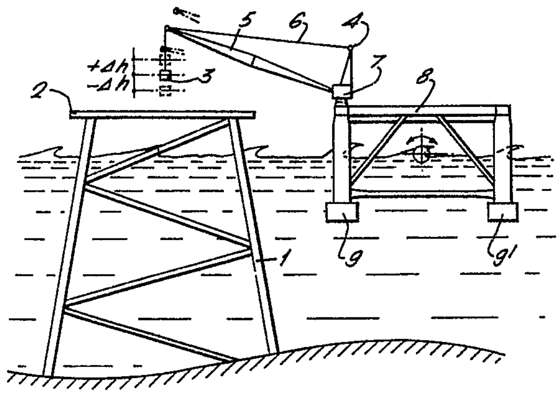



*Fig. 2.*

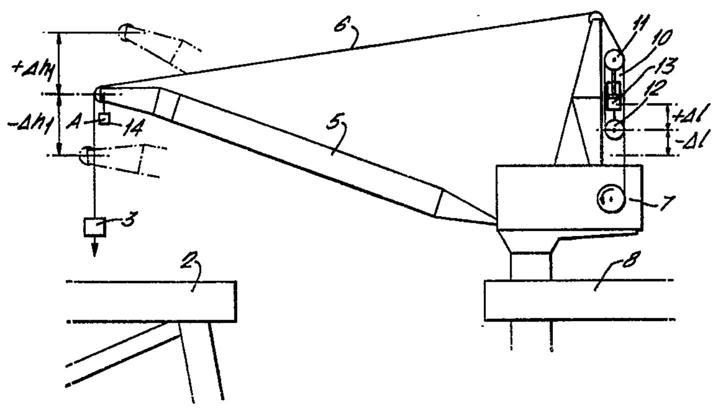
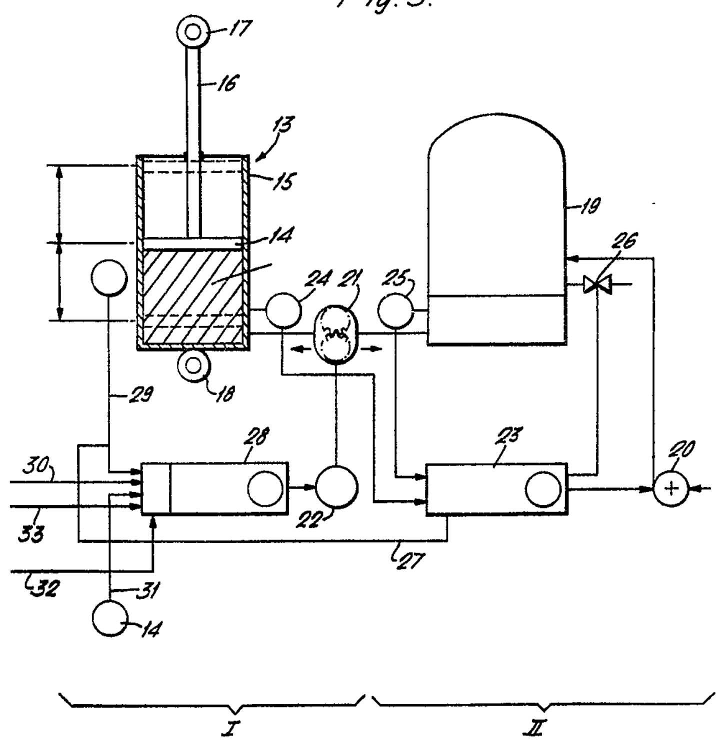


Fig. 3.



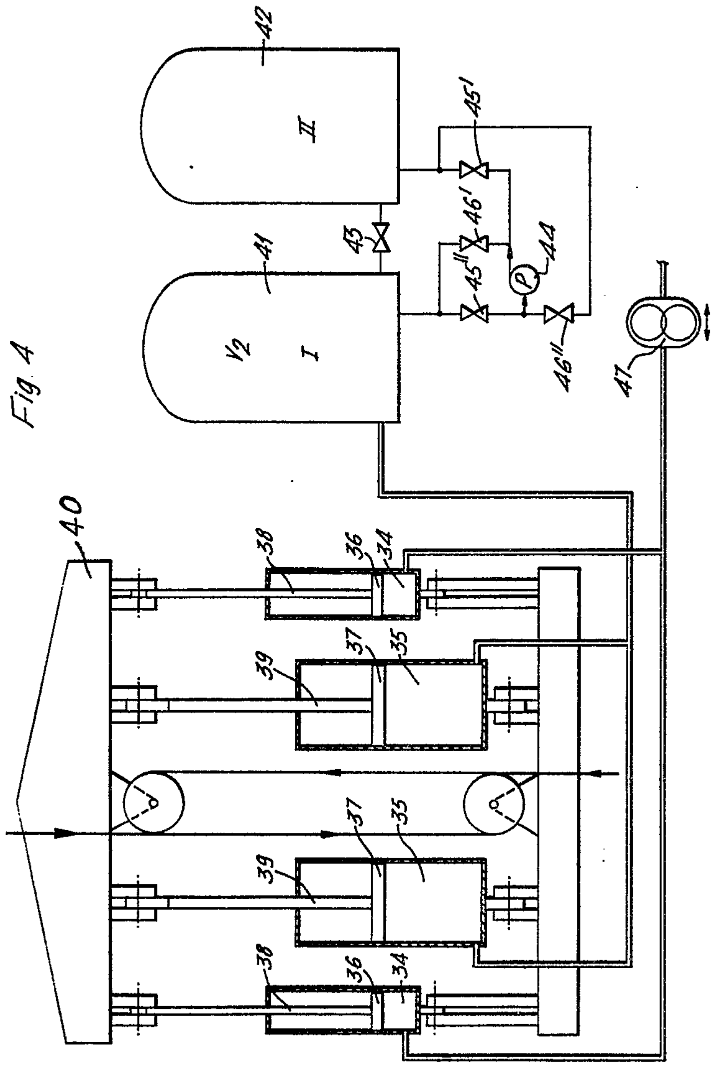



Fig 4

Fig. 5a.

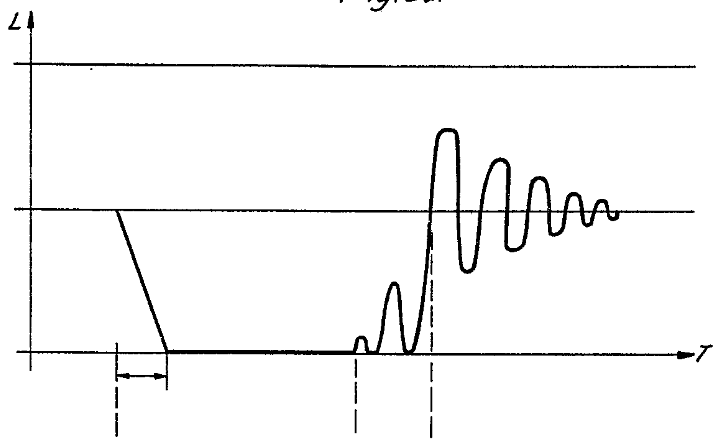



Fig. 5b.

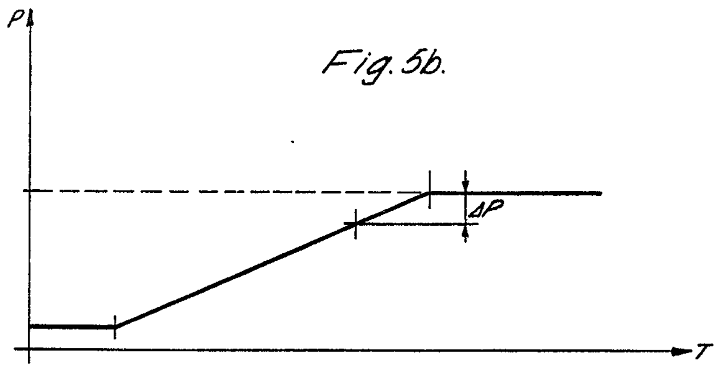


Fig. 6.

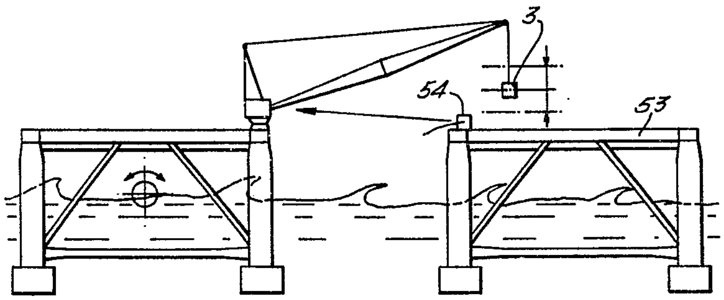
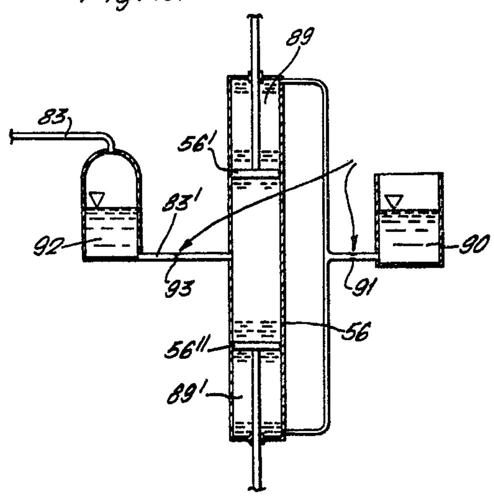



Fig. 10.



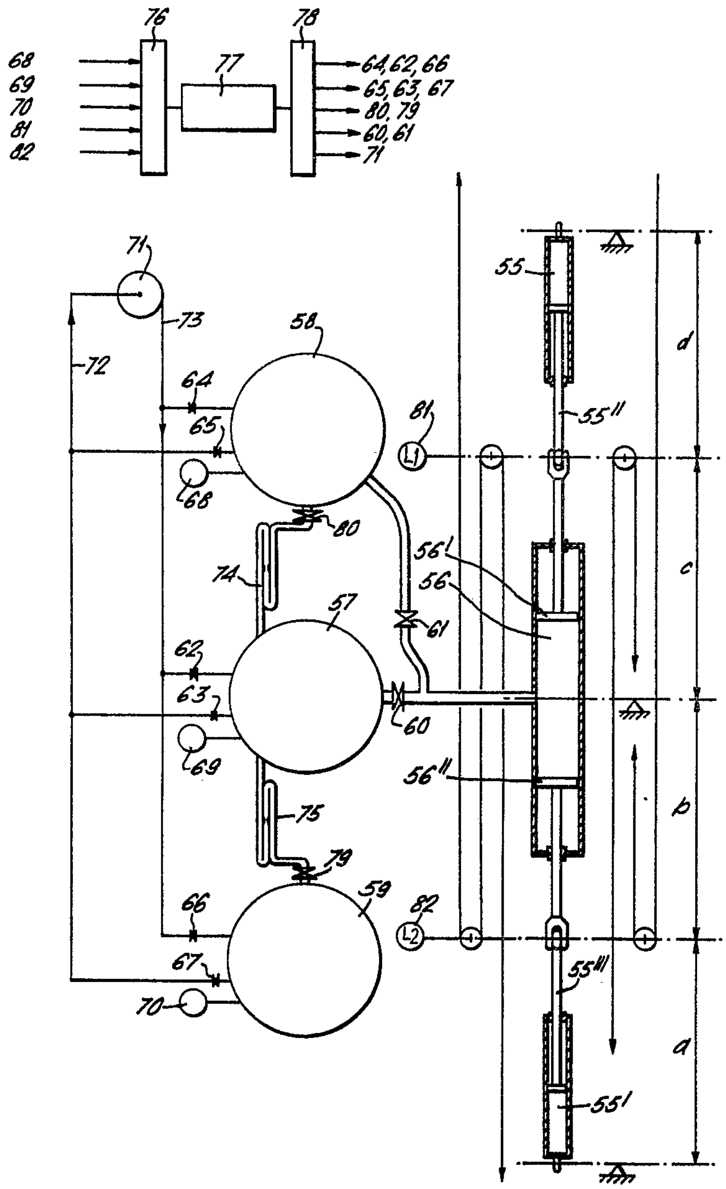

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Fig. 8.

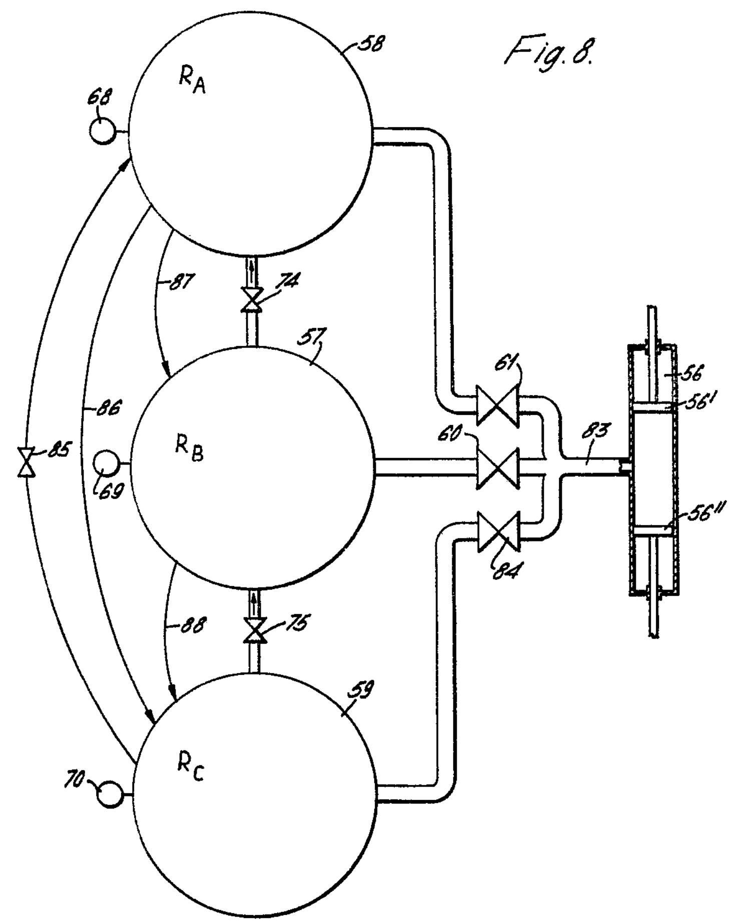

Fig. 9.