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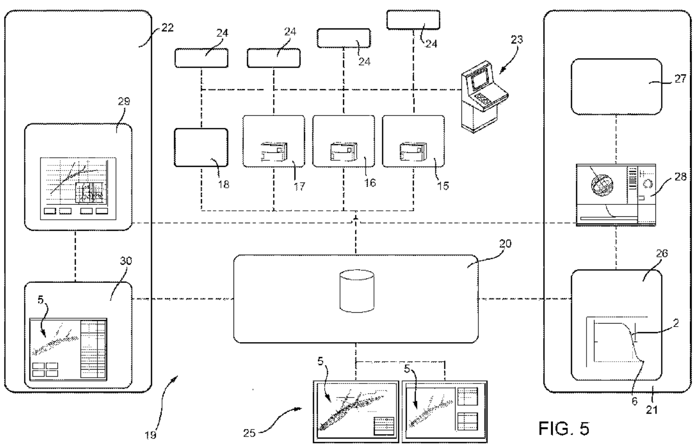

FIG. 5

(57) **Abstract**: An electronic control system for controlling a variable- configuration lay ramp of a pipeline laying vessel, to lay a pipeline on the bed of a body of water, is configured to : acquire data including data related to the configuration of the lay ramp (5), data related to the laying vessel (1), and data related to the forces transmitted by the lay ramp (5) and the laying vessel to the pipeline (2); generate a plurality of step sequences to change the configuration of the lay ramp (5) from a first to a second work configuration; and select a best step sequence as a function of the plurality of step sequences and the acquired data, so as to minimize the stress induced in the pipeline (2) at each intermediate configuration between the first and second work configuration.

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ELECTRONIC SYSTEM, METHOD, AND PROGRAM FOR CONTROLLING A VARIABLE-CONFIGURATION LAY RAMP OF A PIPELINE LAYING VESSEL, TO LAY A PIPELINE ON THE BED OF A BODY OF WATER

TECHNICAL FIELD

The present invention relates to an electronic control system for controlling a variable-configuration lay ramp of a pipeline laying vessel, to lay an underwater pipeline on the bed of a body of water.

BACKGROUND ART

Lay ramps of pipeline laying vessels are normally of variable-configuration design. That is, a lay ramp normally comprises a number of segments hinged to one another and to the laying vessel; and a number of pipeline supports. The position of each segment is adjustable with respect to the laying vessel and/or to the other segments, and each support is fitted adjustably to one of the segments to minimize the forces transmitted to the pipeline, and to define a pipeline configuration designed to minimize stress induced in the pipeline. A lay ramp of this type is described in the Applicant's Patent Application WO 2011/086100 A2. When laying the pipeline, the lay ramp configuration normally varies slightly to adapt to changing external conditions or to operating parameters of the laying vessel. When laying work is stopped by bad weather, the pipeline is abandoned on the bed of the body of water, and the lay

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ramp is set to a safety configuration above water.

When the topography of the bed along which the pipeline is to be laid varies considerably, the configuration of the lay ramp varies widely between a first and second work configuration. In this connection, it is important to remember that a path along which to lay the pipeline is determined beforehand, and extends inside a laying corridor, i.e. a theoretical strip along the bed of the body of water. To avoid overstressing the pipeline, this is normally abandoned before changing the configuration of the lay ramp.

Any discussion of documents, acts, materials, devices, articles or the like which has been included in the present specification is not to be taken as an admission that any or all of these matters form part of the prior art base or were common general knowledge in the field relevant to the present disclosure as it existed before the priority date of each claim of this application.

Throughout this specification the word "comprise", or variations such as "comprises" or "comprising", will be understood to imply the inclusion of a stated element, integer or step, or group of elements, integers or steps, but not the exclusion of any other element, integer or step, or group of elements, integers or steps.

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DISCLOSURE OF INVENTION

Embodiments of the present invention aim to provide an electronic control system for controlling a lay ramp of a laying vessel for laying an underwater pipeline on the bed of a body of water, wherein the electronic control system allows to change the configuration of the lay ramp between a first and second work configuration without abandoning the pipeline, and while at the same time maintaining acceptable induced stress in the pipeline.

According to the present invention, there is provided an electronic control system for controlling a variable-configuration lay ramp of a pipeline laying vessel, to lay a pipeline on the bed of a body of water; the electronic control system being configured to : process data related to the lay ramp, data related to the laying vessel, and data related to stress induced in the pipeline; generate a plurality of step sequences to change the configuration of the lay ramp from a first to a second work configuration; and select a best step sequence as a function of the plurality of step sequences and the acquired data, so as to minimize the stress induced in the pipeline at each intermediate configuration between the first and second work configuration.

The system according to the present invention

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provides for selecting the step sequence best designed to maintain acceptable induced stress in the pipeline. Proceeding in steps also makes it easier to monitor changes induced by the altered configuration of the lay ramp.

Accordingly, the electronic control system is preferably configured to transmit commands to the lay ramp to implement at least one step in the best step sequence. Operating this way, checks as described below can be made after the step in the best step sequence is performed.

In a preferred embodiment of the present invention, the electronic control system is configured to assign to each step in the best step sequence estimated values related to the intermediate configuration of the lay ramp; acquire data related to the configuration of the lay ramp in the intermediate configuration, and consistent with the estimated values; and compare the estimated values with the acquired data.

The estimated values assigned to each step are values related to a lay ramp configuration and calculated before the lay ramp is set to that particular configuration, whereas the acquired data is data related to a lay ramp configuration and acquired when the lay ramp is actually in that particular configuration.

The estimated values and acquired data are

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homogeneous and therefore comparable. To compare them, the estimated values and acquired data are normally related to the geometric configuration of the lay ramp and/or to the forces exchanged between the lay ramp and the pipeline.

Depending on the outcome of the comparison, the electronic control system decides whether or not to continue implementing the best step sequence. More specifically, the electronic control system is configured to transmit commands to implement at least one further step in the best step sequence, when the difference between the estimated values and the acquired data related to the intermediate configuration of the lay ramp satisfies given acceptance criteria.

The electronic control system is also configured to disable implementation of further steps in the best step sequence, when the difference between the estimated values and the acquired data related to the intermediate configuration of the lay ramp does not satisfy given acceptance criteria.

In this case, a new strategy must be defined to change the configuration of the lay ramp from the intermediate configuration to the second work configuration. Accordingly, the electronic control system is configured to generate another plurality of step sequences to change the configuration of the lay

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ramp from an intermediate configuration to the second work configuration; and select a further best step sequence as a function of the plurality of step sequences and the acquired data, so as to minimize the stress induced in the pipeline at each intermediate configuration between the initial intermediate configuration and the second work configuration.

In other words, a further best step sequence, selected using the same criteria as for the previous best step sequence, is proposed.

The optimization method used to determine the best step sequence and any further best step sequences is preferably based on genetic algorithms.

That is, the plurality of step sequences corresponds to a population of individuals, and each step sequence corresponds to an individual. Selection is typically based on a so-called fitness function, which, in this case, is preferably related to the stress induced in the pipeline. When applied to each individual/step sequence, the fitness function assigns a score to the population of individuals, and eliminates individuals with lower scores.

The remaining individuals/step sequences are combined using the crossover technique, which, in this case, generates a new-generation step sequence by combining two portions of formerly first-generation

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sequences. The substitution technique may also be used in this case to generate new individuals.

Generally speaking, the stress induced in the pipeline is real-time monitored. The pipeline is substantially subjected to external forces transmitted by the laying vessel and lay ramp, and to predominantly flexural stress produced by the configuration of the pipeline between the laying vessel and the bed of the body of water.

In a preferred embodiment of the present invention, the electronic control system is configured to acquire the forces transmitted by the laying vessel and lay ramp to the pipeline.

These forces are easily detectable using sensors located on supports along the lay ramp, and on tensioning devices for releasing the pipeline in controlled manner from the laying vessel.

In a preferred embodiment of the present invention, the electronic control system is configured to calculate the stress induced in the pipeline by the pipeline’s configuration between the laying vessel and the bed of the body of water.

More specifically, the electronic control system is configured to calculate a configuration of the pipeline between the laying vessel and the bed of the body of water; to define a finite-element model of the pipeline;

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and to calculate the stress induced in the pipeline.

Real-time control of the pipeline is designed to indicate stress approaching critical levels, and to inform personnel so that appropriate steps may be taken to prevent it from exceeding critical levels. Monitoring stress induced in the pipeline also provides reference parameters by which to define the fitness function.

In a preferred embodiment of the present invention, the electronic control system comprises a centralized monitoring system configured to acquire, monitor, and memorize detectable data related to the lay ramp and the laying vessel; and a laying guidance system connected to the centralized monitoring system and configured to real-time monitor the stress induced in the pipeline.

In other words, the electronic control system architecture preferably comprises two systems with different functions and interfaced to exchange information.

In a preferred embodiment of the present invention, the electronic control system comprises a lay ramp management system comprising a computer planner configured to implement an optimization program to determine the best step sequence, and a computer scheduler for implementing and checking the steps.

The computer planner is connected to the laying guidance system to acquire stress data, which is used to

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define the fitness function.

The computer scheduler is connected to the centralized monitoring system to acquire data related to the homogeneous characteristics of the estimated values.

The estimated values preferably include estimated values related to the lay ramp configuration and/or to the forces exchanged between the lay ramp and the pipeline.

They may also include stress induced in the pipeline.

In a preferred embodiment of the present invention, the electronic control system is configured to generate a first number of step sequences with a first given step, and a second plurality of step sequences with a second given step, to change the configuration of the lay ramp from a first to a second work configuration; and select at least a first and a second best step sequence as a function of the acquired data and, respectively, of the first and the second plurality of step sequences, so as to minimize stress induced in the pipeline at each intermediate configuration between the first and second work configuration; the first given step being greater than the second given step.

Being greater than the second given steps, the first given steps obviously change the lay ramp configuration faster, but the first best step sequence

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presumably produces greater stress in the pipeline – or, at any rate, is riskier – than the second best step sequence. In which case, it is up to the operator to decide which best step sequence to implement under the circumstances.

In a preferred embodiment of the present invention, the electronic control system is associated with a lay ramp, which comprises a plurality of interconnected, adjustable-tilt segments, and a plurality of adjustable supports fitted to the segments. Each step in a step sequence corresponds to movement of a segment of a support.

The step sequence is therefore a sequence of movements of the segments and supports.

Another object of the present invention is to provide a method of controlling a variable-configuration lay ramp of a laying vessel, to lay a pipeline on the bed of a body of water, and which enables substantial changes in the configuration of the lay ramp without abandoning the pipeline, and without inducing excessive stress in the pipeline.

According to the present invention, there is provided a control method for controlling a variable-configuration lay ramp of a pipeline laying vessel, to lay a pipeline on the bed of a body of water; the control method comprising the stages of acquiring data

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related to the configuration of the lay ramp, data related to the laying vessel, and data related to stress induced in the pipeline; generating a plurality of step sequences to change the configuration of the lay ramp from a first to a second work configuration; and selecting at least one best step sequence as a function of the plurality of step sequences and the acquired data, so as to minimize the stress induced in the pipeline at each intermediate configuration between the first and second work configuration.

The present invention also includes a computer program loadable directly into a computer memory to perform the stages in the method; and a program product comprising a readable medium on which the program is memorized.

BRIEF DESCRIPTION OF THE DRAWINGS

A non-limiting embodiment of the present invention will be described by way of example with reference to the attached drawings, in which :

Figure 1 shows a side view, with parts removed for clarity, of a laying vessel with a lay ramp in a first work configuration to lay a pipeline on the bed of a body of water;

Figure 2 shows a side view, with parts removed for clarity, of the Figure 1 laying vessel with the lay ramp in a second work configuration to lay the underwater

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pipeline;

Figure 3 shows a larger-scale side view, with parts removed for clarity, of the lay ramp in the first work configuration;

Figure 4 shows a side view, with parts removed for clarity, of the Figure 1 lay ramp in the second work configuration;

Figure 5 shows a schematic block diagram, with parts removed for clarity, of an electronic control system for controlling the lay ramp.

BEST MODE FOR CARRYING OUT THE INVENTION

Number 1 in Figures 1 and 2 indicates as a whole a laying vessel for laying a pipeline 2 on the bed 3 of a body of water 4. The bathymetry of bed 3 of body of water 4 varies from a minimum along the shoreline, to a maximum, normally far offshore. Planning the laying of pipeline 2 on bed 3 comprises selecting the best path on the basis of project parameters, to define the best course for laying vessel 1 to follow when laying pipeline 2. Laying vessel 1 is equipped with a lay ramp 5 for guiding pipeline 2 as it is being laid. Figures 1 and 2 show laying vessel 1 in relatively shallow and relatively deep water respectively. In Figure 1, lay ramp 5 is set to a first work configuration characterized by a gradual curve; in Figure 2, it is set to a second work configuration characterized by a sharp

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curve.

In Figure 1, the pipeline 2 configuration is substantially S-shaped, sloping gradually between laying vessel 1 and bed 3, and characterized by a relatively small exit angle (with respect to the horizontal) of pipeline 2 from lay ramp 5. In Figure 2, the pipeline 2 configuration is substantially in the form of a steeply sloping 'S', characterized by a relatively wide exit angle of pipeline 2 from lay ramp 5. Pipeline 2 contacts bed 3 at a so-called touch-down point (TDP) 6, which is an important parameter to ensure pipeline 2 is actually being laid along the set best path, and to determine the configuration of pipeline 2 between bed 3 and laying vessel 1.

THE LAYING VESSEL

With reference to Figure 1, laying vessel 1 comprises a floating structure 7, and an assembly line 8 for assembling unit-length pipe sections (not shown) into pipeline 2. Assembly line 8 comprises tooling (not shown) for preparing and welding the ends, and for coating the welded ends, of the pipe sections. With reference to Figure 3, laying vessel 1 comprises tensioning devices 9 (only one shown in Figure 3) for gripping and releasing pipeline 2 in controlled manner from laying vessel 1. Tensioning device 9 subjects

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pipeline 2 to mainly tensile stress produced by the normally opposing forces exerted on pipeline 2 by laying vessel 1 and by the part of pipeline 2 downstream from tensioning device 9. Though Figure 3 shows only one tensioning device 9, laying vessel 1 normally comprises a plurality of tensioning devices 9 arranged in series along pipeline 2.

Laying vessel 1 is moved, normally in steps, along the set course by a drive module 10 (Figures 1 and 2), which controls its travelling speed and course.

THE LAY RAMP

With reference to Figures 3 and 4, lay ramp 5 is hinged to laying vessel 1, and comprises a plurality of articulated segments 11, 12, 13; and a plurality of pipeline supports 14 fitted to segments 11, 12, 13. More specifically, each segment 11, 12, 13 is fitted with at least one support 14.

Lay ramp 5 comprises actuating assemblies 15, 16, 17 for moving segments 11, 12, 13; and actuating assemblies 18 for moving respective supports 14. More specifically, actuating assemblies 15, 16, 17 are connected to, and designed to adjust the position of, respective segments 11, 12, 13. More specifically, actuating assembly 15 connects segment 11 to laying vessel 1. Segment 11 being hinged directly to laying

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vessel 1, actuating assembly 15 provides for adjusting the angular position of segment 11 with respect to laying vessel 1. Actuating assembly 16 connects segment 12 to laying vessel 1. Segment 12 being hinged to segment 11, actuating assembly 16 provides for adjusting the angle between segments 12 and 11.

Actuating assembly 17 is connected to segments 12 and 13. Segments 12 and 13 being hinged to each other, actuating assembly 17 provides for adjusting the angle between segments 12 and 13.

Each support 14 comprises an actuating assembly 18 for adjusting the position of the support with respect to the segment 11, 12, 13 to which it is fitted.

The positions of segments 11, 12, 13 and supports 14 define the path of pipeline 2 along lay ramp 5, and the configuration of pipeline 2 between lay ramp 5 and bed 3. Supports 14 must preferably all contact pipeline 2 simultaneously.

LAY RAMP ELECTRONIC CONTROL SYSTEM

Laying vessel 1 comprises an electronic control system 19 for controlling lay ramp 5. Though the following description refers specifically to the lay ramp 5 shown in the attached drawings, the general operating principles of the electronic control system also apply to lay ramps of other designs. Electronic

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control system 19 preferably comprises a centralized monitoring system (CMS) 20 configured to acquire, store, and display detectable data related to the equipment of laying vessel 1, to lay ramp 5, and to pipeline 2 (Figure 1); a pipe-laying guidance system (PLG) 21 configured to real-time calculate the configuration of pipeline 2, and the stress induced in pipeline 2 as it is being laid, on the basis of the data acquired by centralized monitoring system 20; a ramp management system (RMS) 22 configured to calculate, program, and control a step sequence by which to change the configuration of lay ramp 5 from the first to the second work configuration, while minimizing induced stress in pipeline 2; and a control console 23 for controlling the laying procedure.

CENTRALIZED MONITORING SYSTEM

Centralized monitoring system 20 is configured to acquire and store data comprising :

- geometrical and mechanical pipeline 2 data;
- laying vessel 1 position data;
- the pipeline 2 laying corridor on bed 3 of body of water 4;
- data related to the configuration of segments 11, 12, 13 of lay ramp 5 (Figure 3);
- data related to the position of each support 14

with respect to respective segment 11, 12, 13 (Figure 3);

- data related to the forces exchanged between pipeline 2 and laying vessel 1, and in particular between pipeline 2 and tensioning device 9 (Figure 3);

- data related to the forces exchanged between pipeline 2 and lay ramp 5 (Figure 3), and in particular between pipeline 2 and supports 14;

- data related to the topography of bed 3 (Figures 1 and 2).

Centralized monitoring system 20 is preferably also configured to acquire and store other data, comprising :

- weather and sea conditions, such as wind, current and wave motion;

- laying vessel 1 speed data;

- data related to touch-down point 6 of pipeline 2 (Figures 1 and 2), when this is detectable by sonar in relatively shallow water, or by underwater remote-operated vehicle (ROV – not shown in the drawings);

- pipeline 2 assembly data;

- data related to the exit angle of pipeline 2 from lay ramp 5 (Figures 3 and 4); and

- data related to the movements of laying vessel 1 in body of water 4, especially movements with six degrees of freedom.

Centralized monitoring system 20 is a supervising

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system for acquiring the above data by means of appropriate sensors 24, and for monitoring and storing the data. Centralized monitoring system 20 comprises a graphic interface 24 showing the whole assembly line 8 and lay ramp 5 (Figures 1 and 2). In the example shown, centralized monitoring system 20 interfaces with the tooling on assembly line 8 (Figure 1), with laying guidance system 21, and with ramp management system 22, and is configurable architecturally to extend the above interfaces and to adapt to lay ramps of different designs.

LAYING GUIDANCE SYSTEM

The main purpose of laying guidance system 21 is to real-time monitor the stress induced in pipeline 2, to prevent overstressing it.

Laying guidance system 21 is configured to calculate the stress induced in pipeline 2 as a function of the data stored in centralized monitoring system 20. Laying guidance system 21 comprises a data validating block 26; a computer 27 equipped with a memory and configured to calculate the configuration of pipeline 2 between lay ramp 5 and bed 3 of body of water 4 (Figures 1 and 2), and the stress induced in pipeline 2; and an operator interface block 28 for assisting the operator in guiding laying vessel 1 (Figures 1 and 2). Computer

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27 employs a program, based on the finite-element model theory, for calculating the configuration of, and the stress induced in, pipeline 2. In other words, laying guidance system 21 validates the data acquired by centralized monitoring system 20; determines the configuration of pipeline 2 between lay ramp 5 and touch-down point 6; constructs a finite-element model of pipeline 2; and calculates stress as a function of forces applied to the model of pipeline 2 and derived from the data stored in centralized monitoring system 20.

RAMP MANAGEMENT SYSTEM

Ramp management system 22 comprises a computer planner 29 and a computer scheduler 30. Computer planner 29 receives information from laying guidance system 21, and is configured to process a program for generating a plurality of step sequences, and selecting a best step sequence as a function of the plurality of step sequences. Each step sequence is capable of changing the configuration of lay ramp 5 from the first to the second work configuration. Each step in a step sequence is associated with movement of one of segments 11, 12, 13 or a support 14 (Figures 3 and 4). Optimization is based on minimizing the risk of overstressing pipeline 2.

The best step sequence is preferably selected using

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combinatorial optimization algorithms, in particular genetic algorithms. A few general principles and applications of genetic algorithms can be found in ‘Introduction to Genetic Algorithms’ by S.N. Sivanandam and S.N. Deepa; published by Springer; first edition (12 December, 2007).

Basically, each step sequence corresponds to an individual, and the plurality of step sequences corresponds to a population of individuals. The selection mechanism is determined by a fitness function, which, in the case in hand, is determined mainly on the basis of the stress values calculated by laying guidance system 21, and therefore takes into account the stress induced in pipeline 2 in the first work configuration. More specifically, the fitness function is defined to assign a better fitness value to an individual with better estimated stress values, than to an individual with worse estimated stress values. The fitness function preferably also takes into account the total time taken to change from the first to the second work configuration.

Computer planner 29 generates a population of individuals using a generating method which may be random, i.e. the steps and relative step sequences are generated randomly or semi-randomly, i.e. individuals are generated with a few predetermined parameters and a

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few random parameters, or are generated randomly within predetermined step value ranges. In other words, the steps in a sequence are generated randomly within predetermined step value ranges.

Computer planner 29 applies the fitness function to the population of individuals; assigns a fitness value to each individual in the population on the basis of the fitness function; and defines a rating, in which individuals are rated according to their respective fitness values, and in which the best fitness values are associated with individuals corresponding to the step sequences best suited to change the configuration of lay ramp 5.

Computer planner 29 selects the individuals assigned the best scores by the fitness function. Computer planner 29 generates a new population of individuals from the selected individuals using a generating technique. Generating techniques comprise, for example, a first so-called crossover technique, by which some parts of at least two selected individuals are combined to generate two new individuals; and a second so-called substitution or mutation technique, by which random changes are made to parts of a number of individuals.

Computer planner 29 defines a new rating of the new individuals by applying the fitness function to the new

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population of individuals; and re-selects the individuals with the best fitness values. Computer planner 29 keeps on generating new populations of individuals on the basis of the previously generated population, until one of a number of stop criteria is met. The stop criteria may, for example, comprise a limit to the number of new populations that can be generated, or the obtaining an individual with a fitness value within a given range.

Whichever the case, computer planner 29 is able to select the individual with the best score, and obtain the best step sequence defined by the selected individual; and calculates the estimated values associated with each step in the best step sequence.

The estimated values preferably include estimated values related to the configuration of lay ramp 5. The estimated values preferably comprise geometric values defining the estimated positions of supports 14 and segments 11, 12, 13 (Figures 3 and 4) and/or values defining the estimated forces exchanged between lay ramp 5 and pipeline 2.

The estimated values may also include predicted values of stress induced in the pipeline.

Computer planner 29 transmits the best step sequence to computer scheduler 30, which communicates the individual steps in the best step sequence to

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centralized monitoring system 20 controlling actuating assemblies 15, 16, 17, 18 (Figures 3 and 4).

Computer scheduler 30 implements a program for executing each step in the best step sequence, and checks that the intermediate configuration after each step is as expected. More specifically, checking consists in determining whether the data acquired by centralized monitoring system 20 after the step is executed, and homogeneous with the estimated values, corresponds with the estimated values, or rather, whether the difference between the estimated values and the acquired data meets predetermined acceptance criteria. If the difference between the acquired data and the estimated values does meet the acceptance criteria, computer scheduler 30 allows at least one further step in the best step sequence to be executed. Conversely, in the event of a significant difference between the acquired data and the estimated values, i.e. non-conformance with acceptance criteria, performance of the best step sequence previously selected by computer planner 29 is interrupted.

Laying guidance system 21, for real-time calculating the stress induced in pipeline 2, supplies updated stress data to computer planner 29, which accordingly defines a new fitness function.

On the basis of the data acquired by centralized

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monitoring system 20, computer planner 29 generates a new plurality of step sequences with a number of steps that takes into account the steps already performed, and selects a new best step sequence using the new fitness function. The new best step sequence is implemented by computer scheduler 30.

That is, using the genetic algorithm, computer planner 29 provides a new best step sequence, which is implemented by computer scheduler 30 as described above; and the above steps are performed until lay ramp 5 is set to the second work configuration.

The method described refers specifically to step sequences for moving lay ramp 5, and in which the steps comprise angular movements of one of segments 11, 12, 13, and preferably linear movements of supports 14. The length of each step, be it angular or linear, is therefore a vital element in moving the lay ramp from a first to a second work configuration. The length of each step, in fact, affects the number of steps in the step sequence, the stress induced in pipeline 2, and the time taken to position lay ramp 5. Step length selection is based substantially on acceptable test-based values, but which vary within a wide range. A first step length selection technique consists in selecting an intermediate step length value in the given range. A second technique consists in selecting multiple step

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length values, and concurrently performing multiple optimization procedures, to provide the operator with a plurality of best step sequences related to respective step lengths. For example, two step lengths may be selected – for the sake of simplicity, a ‘long step’ and a ‘short step’. The best ‘long-step’ sequence will position lay ramp 5 faster and produce a given stress in pipeline 2; whereas the best ‘short-step’ sequence will take longer to position lay ramp 5 and, presumably, will produce less stress than the best ‘long-step’ sequence.

The operator may thus select the best step sequence best suited to the circumstances at the time.

The advantages of the present invention lie in ensuring a high degree of safety, to reposition the lay ramp without abandoning the pipeline.

Clearly, changes may be made to the embodiment described of the present invention without, however, departing from the protective scope of the accompanying Claims. More specifically, though the preferred embodiment described of the present invention refers to a plurality of computers, each for implementing a specific computer program, the present invention also includes embodiments comprising different plurality of computers from those described, and even only one computer and one program.

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CLAIMS

1) An electronic control system for controlling a variable-configuration lay ramp of a pipeline laying vessel, to lay a pipeline on the bed of a body of water; the electronic control system being configured to : acquire data related to the configuration of the lay ramp, data related to the laying vessel, and data related to stress induced in the pipeline; generate a plurality of step sequences to change the configuration of the lay ramp from a first to a second work configuration; and select at least one optimal steps sequence as a function of the plurality of steps sequences and the acquired data, so as to minimize the stress induced in the pipeline at each intermediate configuration between the first and second work configuration.

2) An electronic control system as claimed in Claim 1, and configured to transmit commands to the lay ramp to implement at least one step in the optimal steps sequence.

3) An electronic control system as claimed in Claim 2, and configured to : assign to each step in the best optimal steps sequence estimated values related to the intermediate configuration of the lay ramp; acquire data related to the configuration of the lay ramp in the

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intermediate configuration, and consistent with the estimated values; and compare the estimated values with the acquired data.

4) An electronic control system as claimed in Claim 3, and configured to transmit commands to implement at least one further step in the optimal steps sequence, when the difference between the estimated values and the acquired data related to the intermediate configuration of the lay ramp satisfies given acceptance criteria.

5) An electronic control system as claimed in Claim 3, and configured to disable implementation of further steps in the optimal steps sequence, when the difference between the estimated values and the acquired data related to the intermediate configuration of the lay ramp does not satisfy given acceptance criteria.

6) An electronic control system as claimed in Claim 5, and configured to : generate another plurality of steps sequences to change the configuration of the lay ramp from an intermediate configuration to the second work configuration; and select a further optimal steps sequence as a function of the plurality of steps sequences and the acquired data, so as to minimize the stress induced in the pipeline at each intermediate configuration between the initial intermediate configuration and the second work configuration.

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7) An electronic control system as claimed in any one of the foregoing Claims, and configured to select the optimal steps sequence using a method based on genetic algorithms, and to construct a fitness function related to the stress induced in the pipeline.

8) An electronic control system as claimed in any one of Claims 1 to 7, and configured to acquire the forces transmitted by the laying vessel and the lay ramp to the pipeline.

9) An electronic control system as claimed in any one of Claims 1 to 8, and configured to calculate the configuration of the pipeline between the laying vessel and the bed of the body of water.

10) An electronic control system as claimed in Claims 8 and 9, and configured to calculate the stress induced in the pipeline.

11) An electronic control system as claimed in any one of the foregoing Claims, and comprising a centralized monitoring system configured to acquire, monitor, and memorize detectable data related to the lay ramp and the laying vessel; and a pipe-laying guidance system connected to the centralized monitoring system and configured to real-time monitor the stress induced in the pipeline.

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12) An electronic control system as claimed in Claim 11, and comprising a lay ramp management system comprising a computer planner configured to implement an optimization program to determine the optimal steps sequence, and a computer scheduler for implementing and checking the steps.

13) An electronic control system as claimed in any one of the foregoing Claims, and configured to generate a first plurality of steps sequences with a first given step, and a second plurality of steps sequences with a second given step, to change the configuration of the lay ramp from a first to a second work configuration; and select at least a first and a second optimal steps sequence as a function of the acquired data and, respectively, of the first and the second plurality of steps sequences, so as to minimize stress induced in the pipeline at each intermediate configuration between the first and second work configuration; the first given step being greater than the second given step.

14) A laying vessel comprising a control system as claimed in any one of the foregoing Claims.

15) A variable-configuration lay ramp of a laying vessel, the lay ramp comprising a plurality of interconnected, adjustable-tilt segments, and a plurality of adjustable supports fitted to the segments; each step in a steps sequence corresponding to movement

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of an element between the segments and the supports; and the lay ramp being operatively connected to a control system as claimed in any one of Claims 1 to 13.

16) A laying vessel comprising a variable-configuration lay ramp as claimed in Claim 15.

17) A control method for controlling a variable-configuration lay ramp of a pipeline laying vessel, to lay a pipeline on the bed of a body of water; the control method comprising the stages of acquiring data related to the configuration of the lay ramp, data related to the laying vessel, and data related to stress induced in the pipeline; generating a plurality of steps sequences to change the configuration of the lay ramp from a first to a second work configuration; and selecting at least one optimal steps sequence as a function of the plurality of steps sequences and the acquired data, so as to minimize the stress induced in the pipeline at each intermediate configuration between the first and second work configuration.

18) A control method as claimed in Claim 17, and comprising the stage of transmitting commands to the lay ramp to implement at least one step in the optimal_step sequence.

19) A control method as claimed in Claim 18, and comprising the stages of assigning to each step in the optimal step sequence estimated values related to the

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intermediate configuration of the lay ramp; acquiring data related to the configuration of the lay ramp in the intermediate configuration, and consistent with the estimated values; and comparing the estimated values with the acquired data.

20) A control method as claimed in Claim 19, and comprising the stage of transmitting commands to the lay ramp to implement at least one further step in the optimal step sequence, when the difference between the estimated values and the acquired data related to the intermediate configuration of the lay ramp satisfies given acceptance criteria.

21) A control method as claimed in Claim 19, and comprising the stage of disabling implementation of further steps in the optimal step sequence, when the difference between the estimated values and the acquired data related to the intermediate configuration of the lay ramp does not satisfy given acceptance criteria.

22) A control method as claimed in Claim 21, and comprising the stages of generating another plurality of steps sequences to change the configuration of the lay ramp from an intermediate configuration to the second work configuration; and selecting a further optimal steps sequence as a function of the plurality of steps sequences and the acquired data, so as to minimize the stress induced in the pipeline at each intermediate

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configuration between the initial intermediate configuration and the second work configuration.

23) A control method as claimed in any one of Claims 17 to 22, and comprising the stages of selecting the optimal steps sequence using an optimization method based on genetic algorithms; and constructing a fitness function related to the stress induced in the pipeline.

24) A control method as claimed in any one of Claims 17 to 23, and comprising the stage of detecting the forces transmitted by the laying vessel and the lay ramp to the pipeline.

25) A control method as claimed in any one of Claims 17 to 24, and comprising the stage of calculating the configuration of the pipeline between the laying vessel and the bed of the body of water.

26) A control method as claimed in Claims 24 and 25, and comprising the stage of calculating the stress induced in the pipeline.

27) A control method as claimed in any one of Claims 17 to 26, and wherein the lay ramp comprises a plurality of interconnected, adjustable-tilt segments, and a plurality of adjustable supports fitted to the segments; each step in a steps sequence corresponding to movement of an element between the segments and the supports.

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28) A control method as claimed in any one of Claims 17 to 27, and comprising the stages of generating a first plurality of steps sequences with a first given step, and a second plurality of steps sequences with a second given step, to change the configuration of the lay ramp from a first to a second work configuration; and selecting at least a first and a second optimal step sequence as a function of the acquired data and, respectively, of the first and second plurality of steps sequences, so as to minimize stress induced in the pipeline at each intermediate configuration between the first and second work configuration; the first given step being greater than the second given step.

29) A computer program loadable directly into a memory of a computer, and designed, when implemented by the computer, to perform the stages in the method as claimed in any one of Claims 17 to 28.

30) A program product comprising a readable medium on which the program in Claim 29 is memorized.

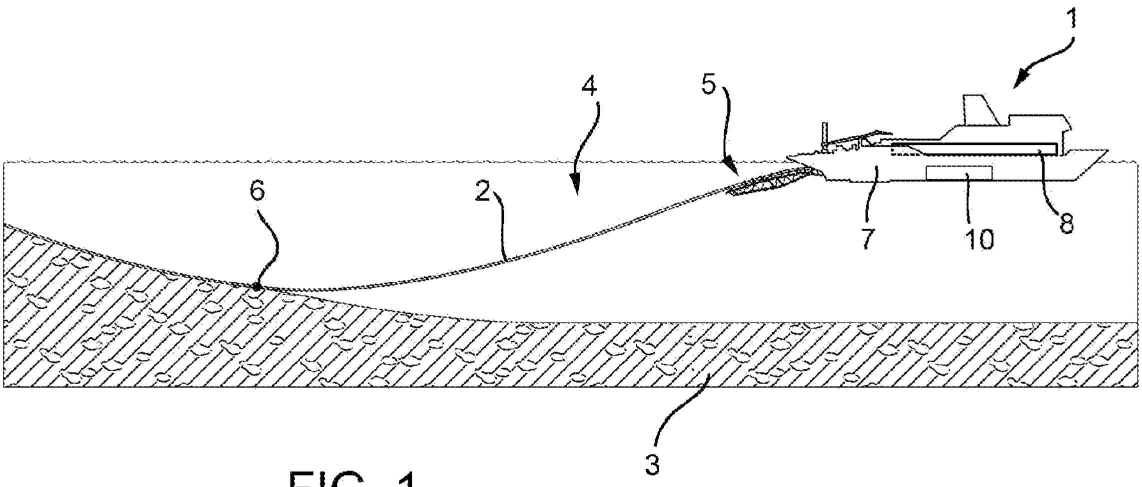
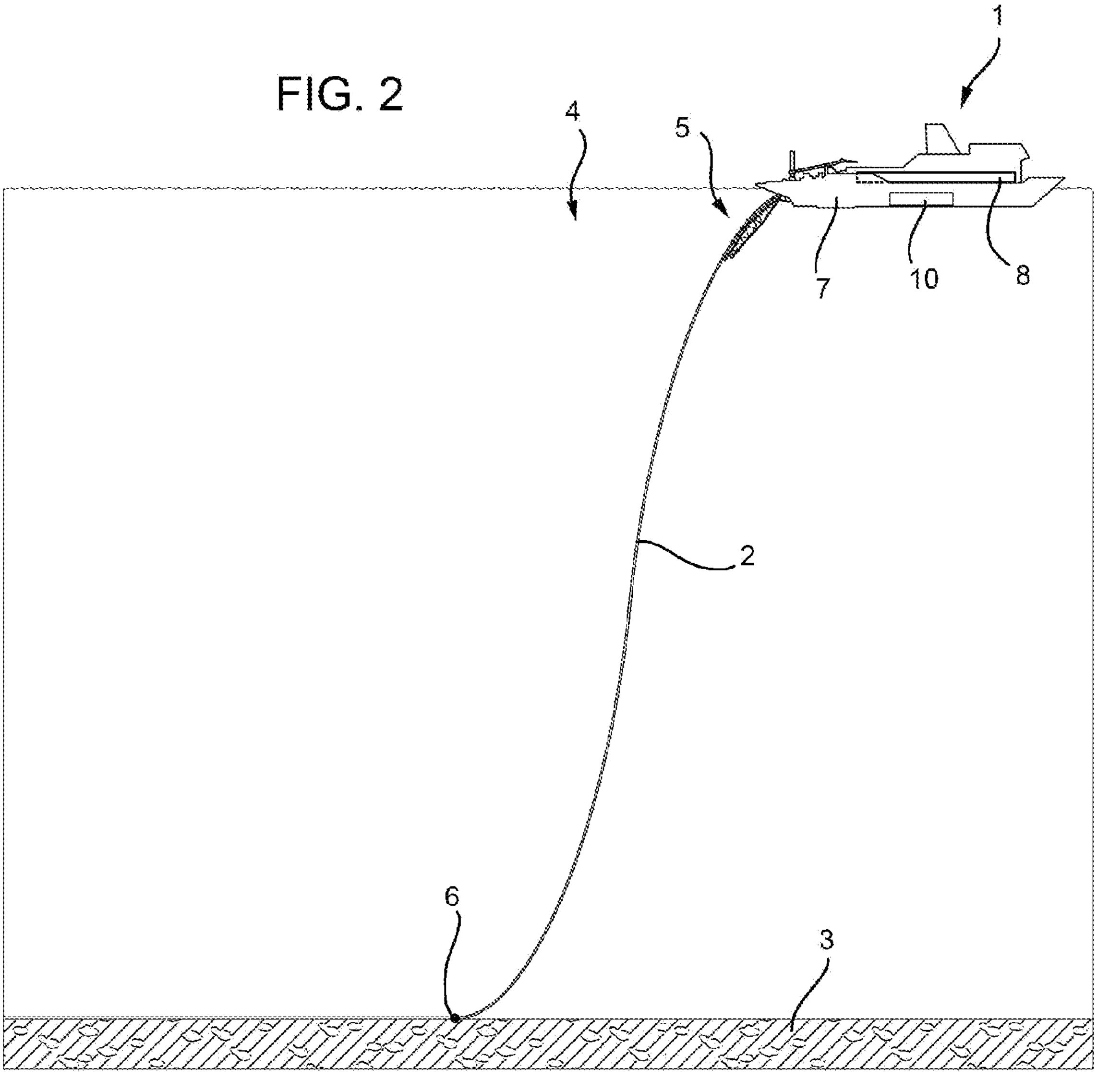


FIG. 1

FIG. 2



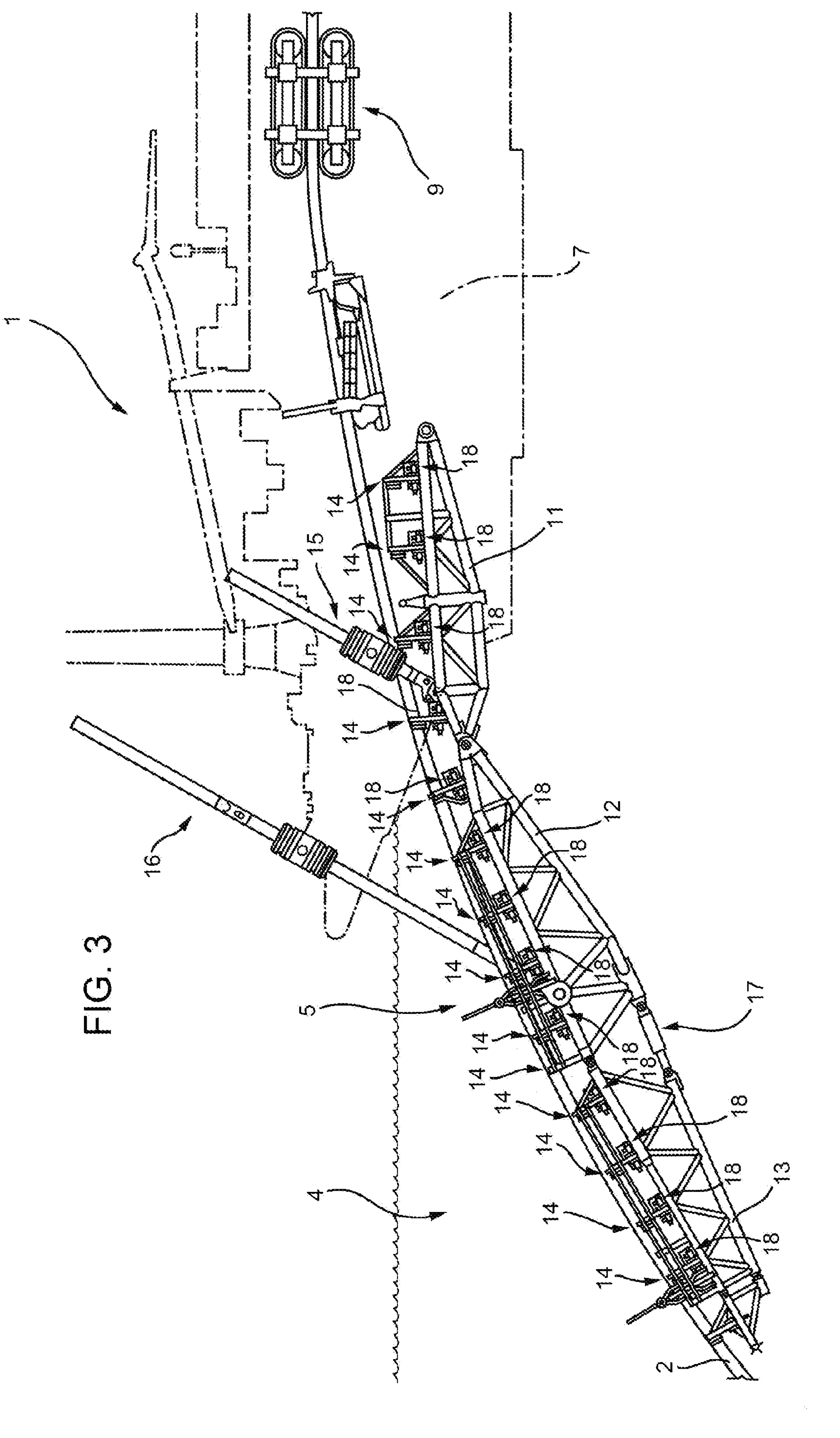


FIG. 3

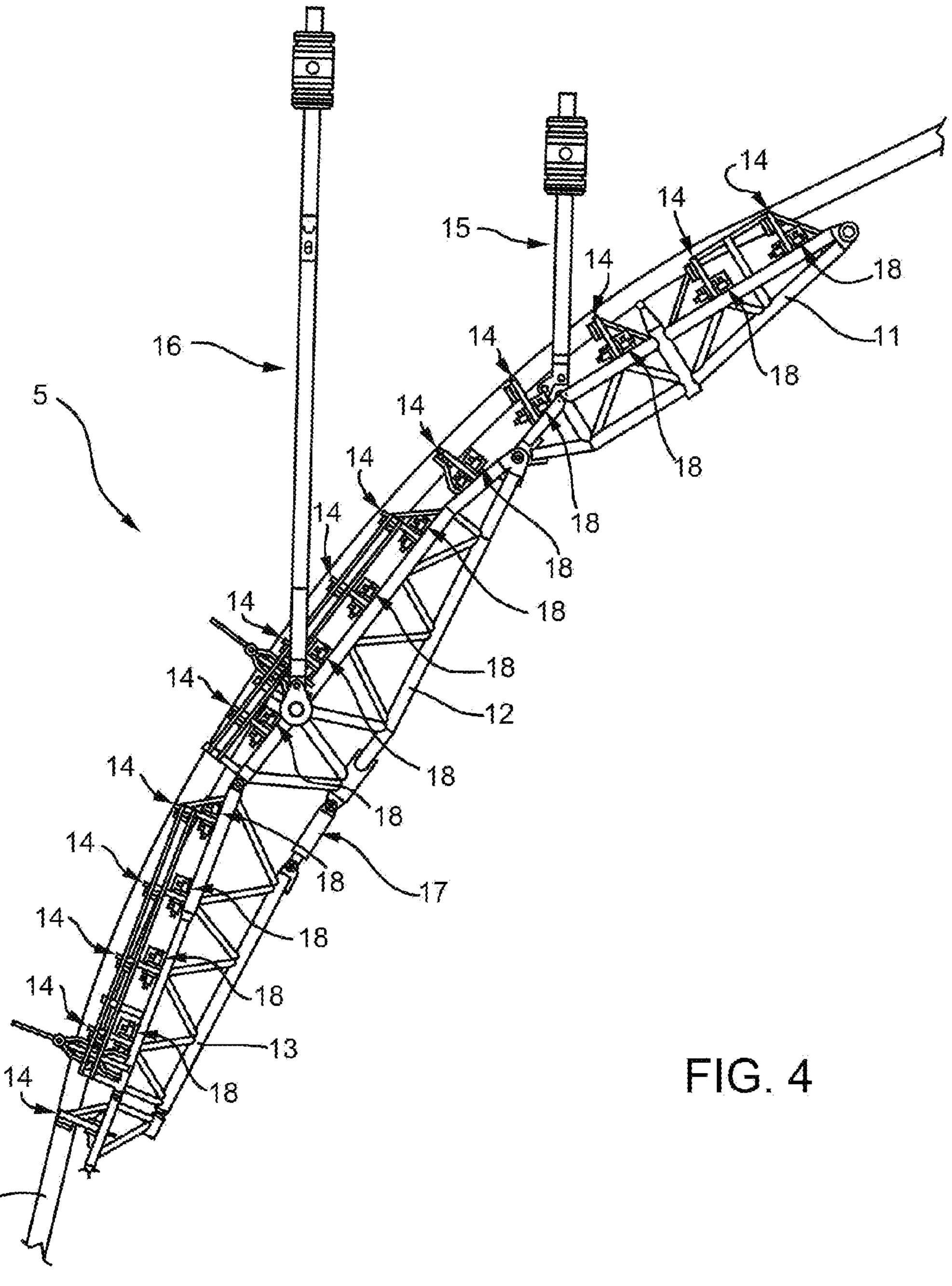

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FIG. 4

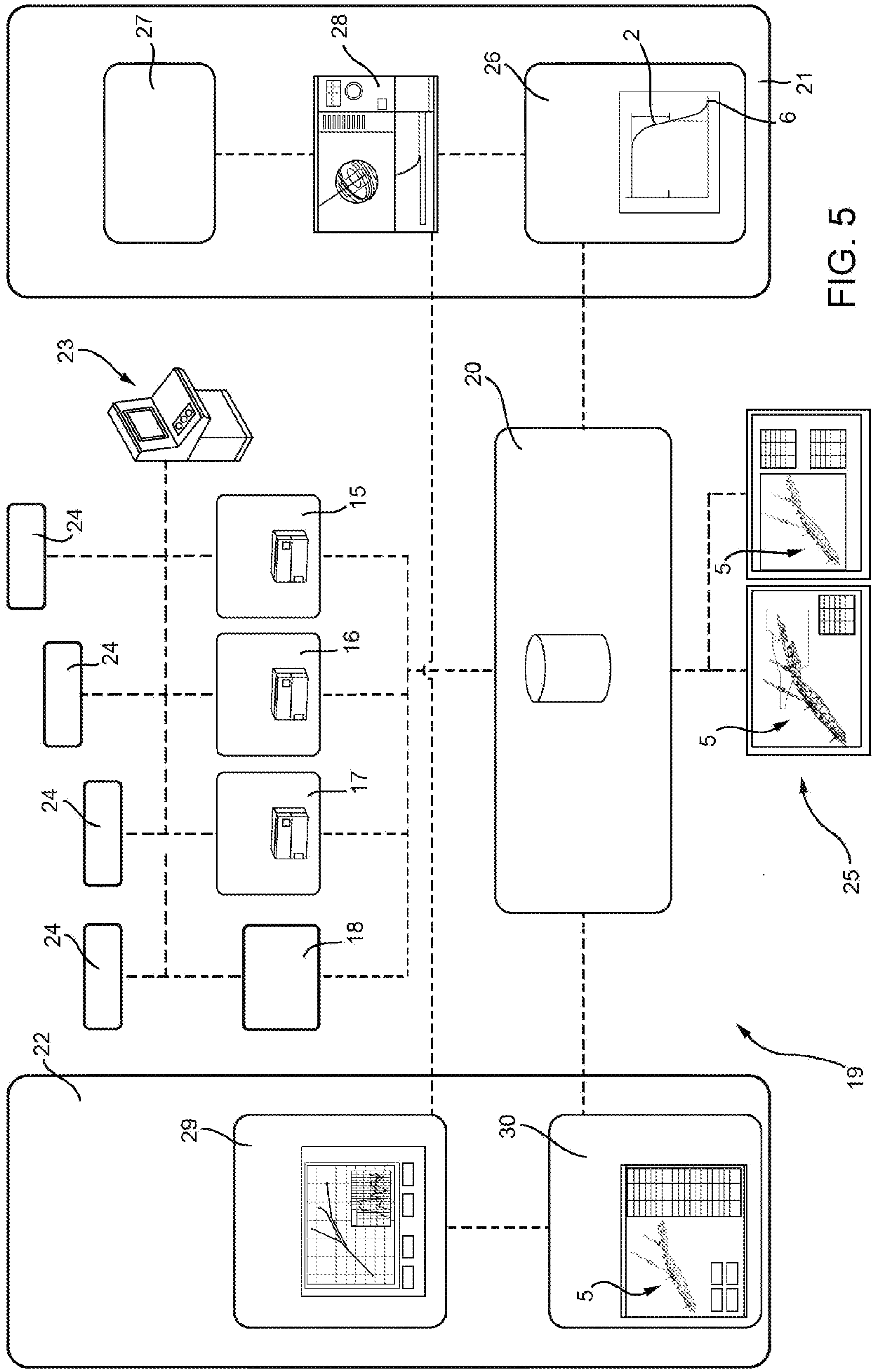

FIG. 5